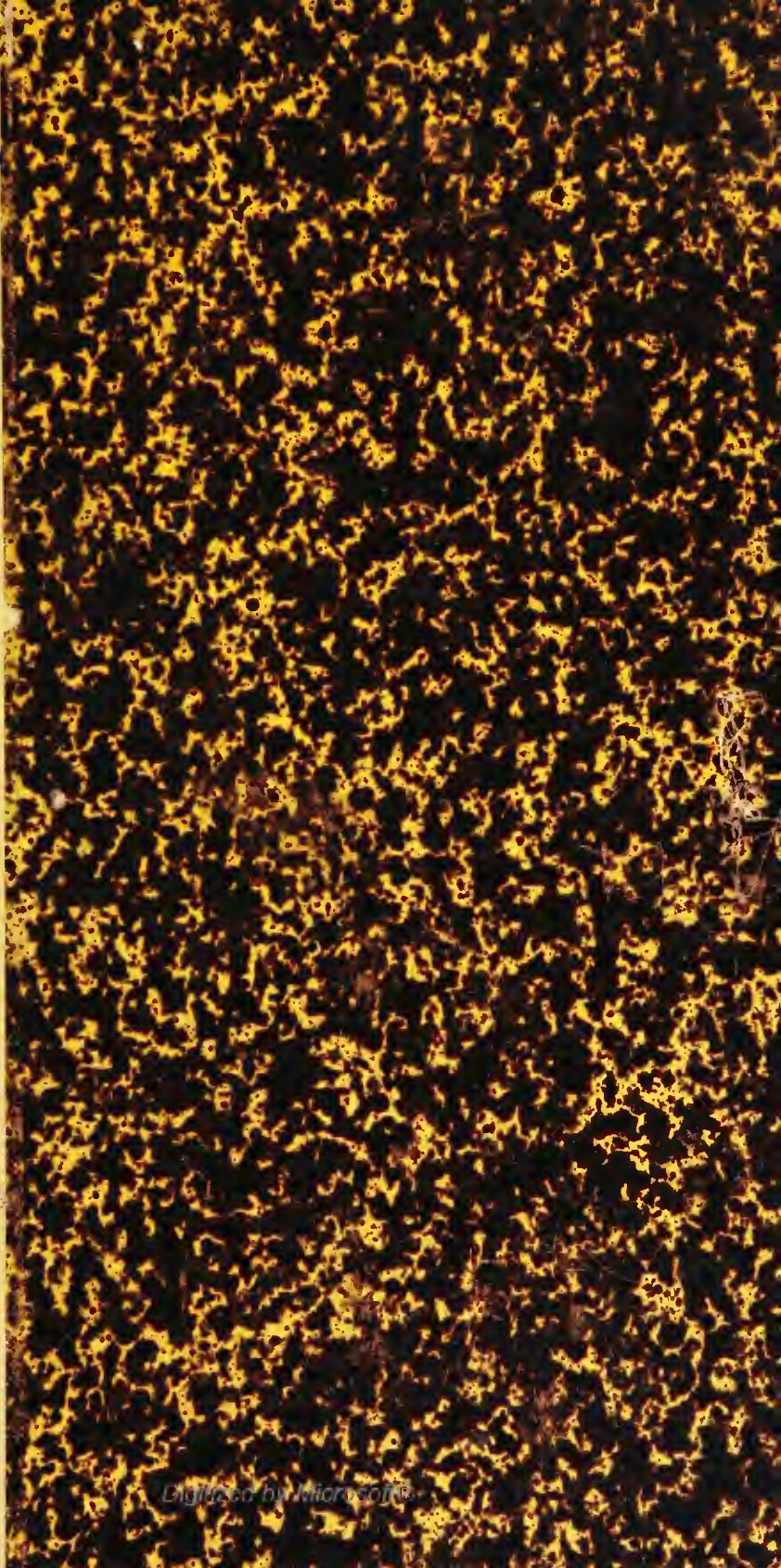
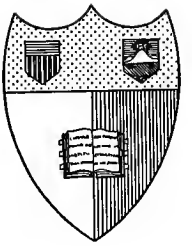




36.

MEMOIRS OF THE GEOLOGICAL SURVEY OF SCOTLAND.

THE

GEOLOGY OF THE SEABOARD OF MID ARGYLL,

INCLUDING

THE ISLANDS OF LUING, SCARBA, THE GARVELLACHS, AND THE LESSER ISLES,

TOGETHER WITH THE NORTHERN PART OF JURA AND A SMALL PORTION OF MULL.

(EXPLANATION OF SHEET 36.)

BY

B. N. PEACH, LL.D., F.R.S., H. KYNASTON, B.A., AND H. B. MUFF, B.A.;

WITH CONTRIBUTIONS FROM

S. B. WILKINSON, J. S. GRANT WILSON, J. B. HILL, R.N., A. HARKER, M.A., F.R.S., E. B. BAILEY, B.A.,

AND PETROLOGICAL NOTES BY

J. S. FLETT, M.B., C.M., D.Sc.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.

GLASGOW:
PRINTED FOR HIS MAJESTY'S STATIONERY OFFICE
BY JAMES HEDDERWICK & SONS LTD.,
AT "THE CITIZEN" PRESS, ST. VINCENT PLACE.

And to be purchased from
W. & A. K. JOHNSTON, LTD., 2 ST. ANDREW SQUARE, EDINBURGH;
E. STANFORD, 12, 13, and 14 LONG ACRE, LONDON;
HODGES, FIGGIS & CO., LTD., GRAFTON STREET, DUBLIN;
From any Agent for the sale of Ordnance Survey Maps; or through any Bookseller from the Ordnance Survey Office, Southampton.

1909.

Price, Two Shillings and Threepence.

LIST OF PUBLICATIONS OF THE GEOLOGICAL SURVEY OF SCOTLAND.

I.—Maps on One-inch Scale.

1. Wigtownshire, South-Western Districts. 4*s*.
2. Wigtownshire, South-Eastern Districts. 4*s*.
3. Wigtownshire, Western Districts. 6*s*.
4. Wigtownshire, East Part; Kirkcudbright, portion of S.W. Division, 6*s*.
5. Kirkcudbrightshire, Southern Districts. 6*s*.
6. Kirkcudbrightshire, E. margin; Dumfriesshire, S. margin. 4*s*.
7. Ayrshire, South-Western Districts. 6*s*.
8. Kirkcudbrightshire, Ayrshire, and Wigtownshire. 6*s*.
9. Kirkcudbrightshire, N.E.; Dumfriesshire, S.W. 6*s*.
10. Dumfriesshire. 6*s*.
11. Roxburghshire and Dumfriesshire. 4*s*.
12. Argyllshire (Kintyre, S. half of). 4*s*.
13. Ayrshire, Turnberry Point, and S. part of Arran (Solid and Drift editions). 4*s*.
14. Ayrshire, Central Districts. 6*s*.
15. Dumfriesshire, N.W.; Ayrshire, S.E.; and Lanarkshire, S. 6*s*.
16. Dumfries, Selkirk, Peebles, Lanark, and Roxburgh shires (parts of). 6*s*.
17. Roxburghshire, Selkirkshire, and Dumfriesshire (parts of). 6*s*.
18. Roxburghshire, E. part. 4*s*.
19. Argyllshire (S. part of Islay). 4*s*.
20. Argyllshire (Kintyre, Gigha I., part of Islay). 4*s*.
21. Argyllshire; Arran, Central and N. part; Bute, S. part; Cumbraes, Ayrshire (part of N.W.) (Solid and Drift editions). 4*s*.
22. Ayrshire, Renfrewshire, Lanarkshire (parts of). 6*s*.
23. Lanarkshire, Central Districts; Ayrshire (part of W.). 6*s*.
24. Peeblesshire, Lanarkshire, Edinburghshire, Selkirkshire (parts of). 6*s*.
25. Berwickshire; parts of Roxburgh, Selkirk, and Edinburgh. 6*s*.
26. Berwickshire and Roxburghshire (parts of). 4*s*.
27. Argyllshire; parts of Islay and Jura, Oronsay. 4*s*.
29. Argyllshire, Ayrshire, Buteshire, Dumbartonshire, and Renfrewshire (parts of). 6*s*.
30. Renfrewshire; parts of Dumbarton, Stirling, Lanark, and Ayr. 6*s*.
31. Lanarkshire, Stirlingshire, Linlithgowshire, Dumbartonshire, Edinburghshire (parts of). 6*s*.
32. Edinburghshire, Linlithgowshire, Fifeshire, Peeblesshire (parts of). 6*s*.
33. Haddingtonshire and parts of Edinburghshire and Berwickshire. 6*s*.
34. Eastern Berwickshire. 4*s*.
36. Seaboard of Mid Argyll (Solid and Drift editions). 2*s*. 3*d*.
37. Mid Argyll (Solid and Drift editions). 6*s*.
38. Perthshire, Stirlingshire, Dumbartonshire, Argyllshire (parts of). 6*s*.
39. Perthshire, Clackmannanshire, Stirlingshire, and Fife (parts of). 6*s*.
40. Fife and Kinross. 6*s*.
41. Fife, East part; Haddingtonshire, North part. 6*s*.
45. Argyllshire, Country near Oban and Dalmally (Solid and Drift editions). 6*s*.
46. Perthshire, Argyllshire (parts of). 6*s*.
47. Perthshire. 6*s*.
48. Perthshire, Forfarshire, and Fifeshire (parts of). 6*s*.
49. Forfarshire and Fifeshire (parts of) 4*s*.
55. Perthshire (Solid and Drift editions). 6*s*.
56. Perthshire, Forfarshire (parts of). 6*s*.
57. Forfarshire and Kincardineshire (parts of). 6*s*.
57A. Kincardineshire, S.E. corner. 4*s*.
60. Rum, Canna, Eigg, Muck. 4*s*.
65. Aberdeenshire, Forfarshire, Perthshire (parts of). 6*s*.
66. Kincardineshire, Forfarshire, Aberdeenshire (parts of). 6*s*.
67. Kincardineshire and Aberdeenshire (parts of). 4*s*.
70. Inverness-shire (West-Central Skye, with Soay). 6*s*.
75. Inverness-shire, Elginshire, Banffshire, Aberdeenshire (parts of). 6*s*.

Easdale Island, with Slate Quarries. Looking west from Port a' Mhuilinn (Seil); on the right, andesite of Lower Old Red Sandstone age overlies Black Slates; in the foreground, 30-foot Raised Beach; Mull in the distance.

36.

MEMOIRS OF THE GEOLOGICAL SURVEY OF SCOTLAND.

THE GEOLOGY OF THE SEABOARD OF MID ARGYLL,

INCLUDING

THE ISLANDS OF LUING, SCARBA, THE GARVELLACHS, AND THE LESSER ISLES,

TOGETHER WITH THE NORTHERN PART OF JURA AND A SMALL PORTION OF MULL.

(EXPLANATION OF SHEET 36.)

BY

B. N. PEACH, LL.D., F.R.S., H. KYNASTON, B.A., AND H. B. MUFF, B.A.;

WITH CONTRIBUTIONS FROM

S. B. WILKINSON, J. S. GRANT WILSON, J. B. HILL, R.N., A. HARKER, M.A., F.R.S., E. B. BAILEY, B.A.,

AND PETROLOGICAL NOTES BY

J. S. FLETT, M.B., C.M., D.Sc.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY

GLASGOW:
PRINTED FOR HIS MAJESTY'S STATIONERY OFFICE
BY JAMES HEDDERWICK & SONS LTD.,
AT "THE CITIZEN" PRESS, ST. VINCENT PLACE.

And to be purchased from
W. & A. K. JOHNSTON, LTD., 2 ST. ANDREW SQUARE, EDINBURGH;
E. STANFORD, 12, 13, and 14 LONG ACRE, LONDON;
HODGES, FIGGIS & CO., LTD., GRAFTON STREET, DUBLIN;
From any Agent for the sale of Ordnance Survey Maps; or through any Bookseller from the Ordnance Survey Office, Southampton.

1909.

Price, Two Shillings and Threepence.

PREFACE.

THIS Memoir describes the geology of the area included in Sheet 36 of the one-inch map of Scotland, which comprises part of the western seaboard of Argyllshire, extending from Easdale and Kilmelfort southwards to the undulating plateau beyond the Crinan Canal, together with the northern portion of Jura, Scarba, Shuna, Luing, Lunga, the Isles of the Sea, and the promontory of Malcolm's Point in the south of Mull.

The greater portion of the area is occupied by the sedimentary and igneous rocks of the metamorphic series in the South-Western Highlands, the reduplication of which by folding is clearly illustrated in the mainland to the north and south of the Crinan Canal. A small portion of the Old Red Sandstone volcanic plateau of Lorne rests unconformably on the crystalline schists to the north of Loch Melfort, while on the promontory of Malcolm's Point in the south of Mull there is a small development of Tertiary basaltic lavas with intrusive sills of dolerite.

A strip of ground on the mainland along the east margin of the Sheet from Kilmartin southwards by the Crinan Canal was mapped by Mr. Hill, and the belt between Kilmartin Burn and Loch Craignish by the late Mr. Wilson. The tract south of the Crinan Canal was surveyed by Dr. Peach, Mr. Bailey, and Dr. Crampton. The area round the head of Loch Craignish and part of Craignish promontory was completed by Mr. Muff, and the plateau beyond in the direction of Kilmelfort and Seil Sound by Dr. Peach and Mr. Kynaston. The metamorphic rocks in Seil and Lunga were mapped by the late Mr. Symes, and those of the Isles of the Sea, Lunga, Scarba, and in the north-west of Jura by Dr. Peach, the remaining portion of Jura being surveyed by Mr. Wilkinson. The Tertiary Igneous Rocks in the south of Mull were examined by Mr. Harker.

The Memoir has been mainly written by Dr. Peach, Mr. Kynaston, and Mr. Muff, with contributions from Mr. Wilkinson, the late Mr. Wilson, Mr. Hill, Mr. Harker, and Mr. Bailey.

The petrographical examination of the rocks has been done partly by Mr. Kynaston, Dr. Flett, and Dr. Teall, and partly by Mr. Hill and Mr. Bailey.

Dr. Ivor Thomas determined the fossils from the shelly clays near Ardfern and in the bed of the Barbreck river.

Two of the epidiorites of this Sheet have been analysed by Mr. E. G. Radley in the Geological Survey Laboratory.

The list of publications referring to the geology of the district has been prepared by Mr. Tait.

The photographs reproduced in Plates I. to VII. have been taken by Mr. Lunn, and the photo-micrographs in Plate VIII. by Mr. T. C. Hall.

The Memoir has been edited by Mr. Hinxman, under instructions from Dr. Horne.

J. J. H. TEALL,
Director.

Geological Survey Office,
28 Jermyn Street, London,
12th January, 1909.

CONTENTS.

Chapter VI.

Chapter VII.

Chapter VIII.

Chapter IX.

Chapter X.

CHAPTER XI.

LIST OF ILLUSTRATIONS.

FIGURES IN TEXT.

EXPLANATION OF SHEET 36.

CHAPTER I.

Physical Features.

The land area embraced in the present sheet is part of that low plateau which fringes the higher and older tableland of the Highland Mountain region and makes up the greater part of Western Argyllshire. It has been carved into hill and valley by streams mostly at a time when the land stood at a higher level than at present. The portion of the map covered by the sea, and representing the plain of that period, now forms part of the Continental-shelf of Europe, while the promontories, islands and skerries represent the hill tops and dividing ridges between the drowned valleys. The whole region, both above and below water, bears evidence of having been powerfully modified by glaciation, while the various raised beaches and corresponding rock-notches which fringe the shores of the mainland and islands, plainly show that the whole area has undergone periodic elevations since glacial times to the extent of at least one hundred feet.

The principal streams in the mainland part of the area are the Add in the south, falling into Loch Crinan; the Barbreck River in the centre, flowing into Loch Craignish; and in the north the Oude, which joins the head of Loch Melfort. Only the lower reaches, however, of these rivers fall within the present map.

The two former streams appear, in part of their course, to occupy consequent valleys, but the geological structure has favoured more rapid erosion in the case of the subsequent streams, and these therefore have played the most important part in producing the present surface relief of the country. The latter have indeed captured portions of the earlier consequent rivers, leaving discontinuous portions of the original transverse valleys, that on the mainland are occupied by comparatively insignificant tributaries, and represented below sea-level by transverse sounds between the islands. It may, for instance, be suggested that the Crinan Loch, the Dorus Mòr (Big Gate), and the Gulf of Corryvreckan represent the seaward extension of the old consequent valley of the Add. Similarly the prolongation of the consequent valley of the Barbreck River may be traced in the hollow, now partly filled with raised-beach deposits, which

divides the Craignish promontory from the high ground south of Loch Melfort, and by the Cuan Sound separating Luing from Seil and Degnish.

The erosion of these valleys dates from a period before the capture of the Add and Barbreck Rivers by the longitudinal tributary of a larger consequent stream, part of whose valley is now represented by the Sound (of Islay) between Jura and Islay.

This capture took place at a time when the sea margin lay at the outer edge of the Continental-shelf.

Differences in the nature and disposition of the rock-masses that enter into this lower plateau have given rise to four distinct types of scenery due to denudation, while a fifth type represents chiefly the results of deposition.

Of these types the first four are each restricted to a particular area, viz.:—

I. The area north of Loch Melfort.
II. The area between Lochs Melfort and Craignish.
III. The rest of the mainland area, together with the islands of Seil, Luing, Shuna, and Torsay.
IV. The islands of Jura, Scarba, Lunga, and the Garvellach Isles.
V. The fifth type of scenery is found in small areas interspersed among the other four districts. B. N. P.

I. To the north of Loch Melfort the ground is mainly occupied by the continuation of the Lorne volcanic series, and consists of a series of lava-flows stretching from the area about the Pass of Melfort westwards to the shores of Seil Sound. There is no very high ground in this area, which constitutes a denuded plateau with an average height of about 450 feet above sea-level, and often with steep slopes towards the sea. The general surface consists of a series of escarpments with a general N.N.E. and S.S.W. trend, that often rise conspicuously above the general level of the ground. These escarpments correspond, as a rule, with the outcrop of the successive lava-flows, and may often be traced for considerable distances across the country, and occasionally rise to over 900 feet above sea-level. Sometimes these features are terminated abruptly by lines of hollow running transversely to them, and marking the position of faults or of later dykes of Tertiary age. Numerous peaty hollows, occasionally occupied by small lochans, lie parallel to the escarpments.

The largest river in this area is the Oude, which enters the map in the north-east corner. For a part of its course the stream lies in a deep narrow gorge in the andesites known as the Pass of Melfort, and forming one of the most conspicuous features in the scenery of the district. On leaving the volcanic rocks, the river enters the lower ground occupied by the older schists, and finally cuts its way to the sea through the raised-beaches at the head of Loch Melfort.

II. On the south side of Loch Melfort the ground has a bolder and more uniform contour, and rises gradually in steep grassy slopes to the height of 1199 feet, at the summit of Tom Soilleir. A well-marked line of watershed is formed by the broad peat-covered ridge extending from Tom Soilleir westwards to Beinn Chaorach (841 feet), and thence to the promontory of An Cnap, and the ground slopes away rapidly to the north and south of this line. H. K.

III. The third type of scenery, as already mentioned, occupies the rest of the mainland and some of the adjacent islands. The rocks entering into these areas belong to the Highland Metamorphic Series, and include altered sedimentary rocks of different resisting power, together with intervening sheets of igneous material. These are arranged in sharp folds, whose longer axes trend approximately N.N.E. and S.S.W. The denudation of this portion of the plateau has produced a series of sharp ridges and hollows, which follow a direction more or less parallel to that of the axes of the folds. The ridges are defined by the outcrops of the more durable igneous rocks, while the intervening valleys have been eroded in the more tractable sediments—the slates, phyllites, and limestones. A series of intermediate and acid dykes of Lower Old Red Sandstone age, which also for the most part follow the trend of the axes of the folds, give rise to minor ridges; while later basic dykes of Tertiary age, cutting the other rocks nearly at right angles, weather out into transverse gaps and hollows. Transverse hollows have also been produced along lines of crush.

In the northern part of the area between Loch Craignish and the Kilmartin Burn the folding is less pronounced than elsewhere, but the transverse hollows are deep, especially that one which has been developed along a line of crush and fault to the south of Dun na Ban-oige and Salachary. The main road runs through this hollow, and some of the troughs into which the strata have been thrown are visible to the passer-by, being well defined by the craggy outcrops of the quartzite and epidiorite. B. N. P.

The relation of geological structure to surface topography is also admirably illustrated in the south-eastern portion of the mainland, where a similar system of parallel ridge and valley, coincident in direction with the long axes of folding, and due to differential erosion of the sedimentary and igneous rocks, forms the characteristic scenery of the district. Here, too, again the prevailing parallel features are crossed at right angles by gullies and clefts running north-north-west, and due to erosion along Tertiary dykes and lines of weakness produced by faults. The islets of rock that protrude from the Crinan Moss are composed almost entirely of epidiorite, which has withstood the ravages of the sea that formerly surrounded them. Dun Add, one of these rocky bosses, is celebrated as the chief fortification of the early Scots or Gaelic colonists from Ireland, who founded the colony of Dalriada and afterwards gave their name to Scotland.

One of the most striking features in this district is the great

cleft south of the Moine Mhòr, which has been taken advantage of in carrying the Crinan Canal from Loch Fyne to the Sound of Jura. To the west of Dunardry this feature forms a singularly straight boundary line between the flat plain of the Crinan Moss and the hills of Knapdale.

The combination of Highland and Lowland scenery which characterises this region is accentuated by the comparative absence of superficial deposits on the higher ground. The sculpture of the uplands is both bold and varied, and corresponds to the diverse types of rock of which they are composed. The beauty of the landscapes is further enhanced by the abundant woodland which clothes the lower slopes. J. B. H.

In the deeply dissected tableland that occupies the area south of Loch Crinan and the Canal the scenery is quite typical. To the east of Loch Coille Bharr the folding is almost vertical, and gives rise to escarpments of epidiorite which form more or less symmetrically closed elliptical rings. West of that loch the axial planes of the folds dip towards the east, giving a westward aspect to the escarpments. B. N. P.

A slight modification in the system of folding and a corresponding change in the character of the scenery is found in that part of the area lying S.S.W. of Loch Crinan.

In its physical features this part of the country belongs to the re-sculptured plateau of Western Argyle. Its highest point is Cnoc Reamhar, 862 feet, situated near the centre of the area. Erosion has everywhere been guided by geological structure. Sills of epidiorite, many times folded, have provided the resistant rock of the district, and now remain as ridges, their lines of ecarpment usually facing W.N.W., and forming cliffs characterised by great slabs and pinnacles due to weathering along joints and cleavage planes.

The quartzite, on the other hand, occupies, as a rule, the lower slopes and hollows, and from its bedded nature affords good examples of differential erosion along strata of unequal resisting power. The surface of the ground may thus be determined over a considerable area by the folding of a bed of superior hardness. A very characteristic feature of the country is the amount of bare rock exposed, drift of any kind being very scarce. The shores are always fringed by a narrow terrace or rock notch, referable to one or other of the raised-beaches. E. B. B.

A modification of the last-described type of scenery is exhibited in the promontory of Craignish and on the islands of Shuna, Luing, Torsay, and Seil. The sedimentary rocks of these areas are quite as much folded as in the other parts of the map, but contain a very much smaller proportion of intervening igneous sheets and harder quartzite bands. The ground has consequently been reduced to a lower and more uniform level, with fewer and less sharply defined features due to outcrops of harder rocks.

The Tertiary dykes, which in the other areas give rise to transverse notches, here often stand out above the general

surface of the ground occupied by the softer phyllites; and, from their superior resisting power to the action of the waves, rise like great walls on the raised-beaches and rock-notches along the coast.

A small outlier of the volcanic rocks of the Lorne plateau occurs in Seil, giving rise to the terraced and flat-topped features that characterise the Old Red Sandstone lavas. (Plate I., Frontispiece.) The narrow strip of country along the eastern side of Scarba occupied by folded slates and phyllites with bands of quartzite, also presents the same characteristic ridge and hollow type of scenery, developed along the axial planes of the folds.

IV. The fourth type of scenery is found among the quartzites of Jura, Scarba, and Lunga. Although the isoclinal folding of these rocks is intense, and there is a considerable variety in the texture and hardness of the different beds, yet they weather more equally than the softer rocks to the east, above which they stand out in so conspicuous a manner. The quartzite ridge of Jura and Scarba, which has a general height of 1000 feet, rising in places to over 1400 feet, appears to be the least dissected portion of the lower plateau left within the area under consideration, just as the isolated cones—the Paps of Jura—in the south-west, outside the map, seem to represent the remains of the Highland tableland. The escarpments due to the isoclinal folding all face to the west, and are most conspicuous on the western side of the main ridge. The main work of denudation seems, however, to be due to the erosion of the streams that cross the strike, those running along the strike having comparatively short courses. The former do not appear to be original consequent streams, but secondary tributaries to the longitudinal ones. The only original consequent valley is probably the hollow now occupied by the Gulf of Corryvreckan, referred to in an earlier paragraph.

In addition to the features due to variation in the nature of the quartzites, a set of north and south rifts and hollows have been produced by the weathering out of a group of cleaved epidiorite dykes intruded after the folding. The courses of the Lealt Burn and other streams which run obliquely across the strike in the northern end of Jura have evidently been determined by the movements which produced the fissures along which these dykes were intruded, and which continued after their intrusion. Many of the stream courses in Scarba have also been determined by these dyke fissures, and the conspicuous hollow which crosses the island from north to south, one-third of its breadth from the east coast, follows the line of a shattered epidiorite intrusion.

The weathering out of the Tertiary basic dykes has given rise to a few smaller clefts in the north of Jura, and to a much greater number in Scarba, Lunga, and the northern islands. These islands are singularly free from drift and the bare rocks almost everywhere well glaciated.

Remains of raised-beaches are found in many sheltered parts of the coast line, the largest patches occurring at Glengarrisdale on

the west and Barnhill on the east side of Jura. High terraces of marine alluvium are also seen along the east coasts of Scarba and Lunga, with corresponding well-marked rock-notches on the west side of these islands. Storm beaches of quartzite shingle and boulders rest here and there upon these rock ledges. The 35-foot raised beach is nearly always accompanied by a cliff, sometimes over 300 feet in height.

The Garvellachs or Isles of the Sea, composed of a central fold of limestone with other sedimentary rocks of varying texture, present a series of plicated ridges, a modification of the features of the quartzite areas. The north-west side of the islands, exposed to the full swing of the Atlantic waves, forms a precipice, the main part of which was carved out contemporaneously with the erosion of the 34-foot rock-notch. This latter feature is splendidly developed along the south-east side of the islands, and is often over 50 yards in breadth. In marked contrast is that part of the coast-line exposed between tides, where the surface of the rocks, still beautifully moulded and striated by the ice which moved outwards in a direction more or less parallel with that of the chain of islets, shows for how comparatively short a period the land has stood at its present level.

V. The fifth class of scenery—that of the terraced plains—due chiefly to the deposition of freshwater and marine alluvium, assisted by intermittent upheavals of the land, is found in isolated areas scattered amongst those of other scenic type. The largest of these areas surrounds the head of the Crinan Loch and extends up the valleys of the River Add and the Kilmartin Burn.

B. N. P.

The continuity of the hill ranges that form the prevailing topography of the Highlands is here broken by a great plain known as the Moine Mhôr or Crinan Moss. That plain, which extends eastwards from Loch Crinan to the main road between Kilmartin and Bridgend, was formerly the bed of a nearly land-locked sea, which is now restricted to the inlet of Loch Crinan. Except at its narrow entrance, this large flat is enclosed by hilly country that rises abruptly from its margins, while the rocky hillocks within the Moss itself are the stranded islands which dotted the ancient sea.

This large plain is extensively covered by peat, but considerable tracts have been reclaimed and brought under the operations of the plough. The alluvial terraces of the River Add, which pursues a winding course from east to west across its surface, also afford large expanses of arable land that reach their greatest extent between Dalnahasaig and Bridgend.

It should be mentioned here that the part of the course of the River Add which falls within this map is below the point where in late glacial times the overflow water from the Loch Awe glacier poured across the watershed into the Add, and thus greatly assisted that river in silting up the sea-loch. This overflow took place before the glacier had decreased to such an extent as to allow the waters of Loch Awe to escape through the

Creagantairbh Pass into the Kilmartin valley, as described below.

To the north the Moss passes gradually into the higher alluvial terraces of Poltalloch, which extend up the valley of Kilmartin as far as the Pass of Creagantairbh. These terraces, which rise in extensive and fertile platforms along the picturesque strath, now watered only by an insignificant stream, were laid down by an earlier river of considerable magnitude, by which Loch Awe discharged its waters into the sea which covered the area now occupied by the Moine Mhòr. The narrow Pass of Creagantairbh, with its sheer rocky walls 300 feet in height, represents the gorge through which that river poured down on to the plains of Kilmartin.*

A very large pothole, seen in its former bed at Gurach, remains as evidence of the volume of the stream which formed the successive terraces that line the valley from the mouth of the gorge to the sea. J. B. H.

Another of these terraced plains extends up the valley of the Barbreck River from the top of Loch Craignish. Near the head of the loch these terraces form part of the two raised-beaches which fringe each side of the loch. Further up the valley each beach merges into a delta and river-terrace, whose level is not constant, but rises up-stream with the rise of the valley-floor. Carved out of these higher terraces is the modern flood-plain of the river itself, which grades down to the present level of Loch Craignish. The wide depression which runs across the head of Craignish is fringed by the gravel terraces of the higher beach, whilst its floor is occupied by the deposits of the 35-foot beach or by peat. Similar alluvial plains have been laid down at the mouths of the two rivers that enter Loch Melfort, and also at the head of Ardmaddy Bay.

Terraced plains corresponding to the various raised beaches are found more or less fringing the coasts of all the inner islands (Plate I., Frontispiece.) On Luing they form, as it were, a network across the island, showing that when the sea-level stood 100 feet higher than at present the island was broken up into an archipelago.

Similar phenomena are found on Shuna, Lunga, and Seil.

B. N. P.

* "Geology of Mid-Argyll (Explanation of Sheet 37)." *Memoirs of Geol. Survey*, 1905, p. 141.

CHAPTER II.

Formations and Groups of Rock and their General Distribution.

The following shows in tabular form the various formations which enter into the composition of the area under consideration.

Recent and Pleistocene.	Freshwater Alluvia.	Peat	
		1st Terrace	
		2nd „	
		3rd „	
	Marine Alluvia.	Present beach	
		1st Raised beach	
		2nd „ „	
		3rd „ „	
	Moraines.		
	Glacial Sand and Gravel.		
	Boulder Clay.		
Lower Old Red Sandstone.	Conglomerates and Sandstones		c^1

Metamorphic Rocks.

Quartzite and Pebbly Grit	x
"Boulder Bed"	
Limestone	λ
Black Schist, Black Slate (Easdale)	g^i
Phyllite (Craignish and Ardrishaig)	I

Igneous Rocks.

Unfoliated.	Contemporaneous.	Basalt of Eocene age	Bi
		Andesite of Lower Old Red Sandstone age	Ac^1
		Tuffs and Agglomerates, of L. Old Red Sandstone age	Zc^1
	Intrusive	Felsite	F
		Porphyrite	P
		Lamprophyre	L
		Dolerite sills	D
		Basalt and dolerite dykes	M
		Quartz-diorite and granite	G
Foliated wholly or in part		Epidiorite	B^G

General Distribution.—With the exception of a small part of the mainland north of Loch Melfort and a still smaller patch upon the Island of Seil, made up of rocks of Old Red Sandstone age, the whole area to be described is occupied by metamorphic rocks traversed by igneous intrusions, and in places overlaid by recent and glacial deposits.

Amid all the complication arising from the intense folding and puckering that the schistose rocks of sedimentary origin have undergone, it is still possible to recognise a certain symmetry in their distribution. A central area extending from Loch Melfort through Craignish and prolonged under sea as far at least as Ruadh Sgeir, in the Sound of Jura, is occupied by grey phyllites with subordinate beds of quartzite and limestone—the "Craignish Phyllites." To the west of Craignish, in the promontory of Degnish and the Island of Shuna, the Craignish phyllites are followed by a belt of dark slates which pass by intercalation into a massive limestone, and form a band whose southern continuation is recognisable in Reisa an t-Sruith, a skerry lying due west from Craignish Point. The limestone belt is succeeded on the west by the main outcrop of black slates, which form the whole of the islands of Luing, Torsay, and Easdale, and the greater part of Seil, and extend westwards across the Sound of Luing to the east coasts of Lunga and Scarba; also forming a small projecting part of Jura. West of the dark slates, a wide belt of quartzite occupies the remainder of these three last-mentioned islands and passes west and north into Guirasdeal, Eilean Dubh Mòr, and Eilean Dubh Beag, and even as far as the Garvellachs. Despite the discontinuous nature of these exposures, it is certain that there cannot be more than one important repetition in the succession as traced westwards from the Craignish phyllites into the quartzites of Scarba and Lunga. The belts of rock encountered in passing outwards from Craignish are as follows:—

1. Belt of grey phyllites .	Craignish, Loch Melfort, Shuna.
2. Black slates . .	Degnish and Shuna.
3. Dark limestones . .	Degnish, Shuna, Reisa an t-Sruith.
4. Black slates . .	Easdale, Seil, Luing, Torsay, Belnahua, Lunga, Scarba, Jura.
5. Quartzites .	Jura, Scarba, Lunga.

It is highly probable that the rocks of Belt No. 4 may be the reappearance of those of No. 2, but, owing to the intervention of the sea, direct evidence bearing on this point has not been obtained.

Much greater difficulty is experienced in determining a sequence when proceeding eastwards from our central belt of the Craignish phyllites. This is partly owing to the intervention of the waters of Loch Craignish and the alluvium of the Barbreck River, and also to the fact that where the rocks appear again to the north they have been so altered by contact with the granite that their original character is masked. This is also

the case at the head of Loch Melfort, where the passage into the dark slates might be expected to occur. A small outcrop of the dark slates and limestone is, however, exposed near Turnallt, on the west side of the Barbreck River near the head of Loch Craignish, which can with confidence be correlated with those of Belt 2 of the above table. East of Barbreck River and Loch Craignish there is a more or less persistent belt of quartzite corresponding to Belt No. 5 of the western area. Further to the east lies a region of much greater superficial complexity, in which the various rock groups no longer run in more or less uniform belts but interweave with one another, owing to the denudation of a highly plicated area in which the individual bands are comparatively thin and the folds of no great amplitude. The schists are, in addition, much invaded by sheets of epidiorite which are folded along with them, and whose superior powers of resistance cause these igneous rocks to occupy proportionately larger areas on the ground.*

In the district south of Loch Crinan and the River Add the same group of rocks occurs, and folded in a similar manner to that just described. The denudation of the folds has not, however, in this case been carried to such an extent, and the greater part of the area is consequently occupied by the quartzite group (5), the underlying black slates, limestones, and grey phyllites only occurring on the more pronounced folds.

In the extreme south-east corner of the sheet is a small area, about one square mile in extent, of grey calcareous phyllites belonging to the widely-distributed group of the Ardrishaig phyllites. Mr. J. B. Hill has correlated the phyllites of the central or Craignish belt with the Ardrishaig group,† a correlation for which the mapping of the present area has afforded strong presumptive evidence.

On the outlying group of islets, known as the Garvellachs or Isles of the Sea, occurs the remarkable boulder-bed first described by Macculloch, and compared by him to "the schistose conglomerate of Isla and Schihallien."‡

Within the metamorphic area, perhaps the most obvious feature is the great prevalence of pre-folding epidiorite intrusions in the east side of the mainland area, their decrease towards the west as exemplified in the Island of Luing, and their entire absence from Scarba, Lunga, and the north end of Jura. The distribution of epidiorite dykes intruded after the folding is exactly the reverse, since they are restricted to these last-mentioned islands. Their general trend is north and south, although some show a W.N.W. and E.S.E. course.

* T. F. Jamieson first recognised the epidiorites as igneous rocks, and noted their great development in North Knapdale. "On the Structure of the South-west Highlands of Scotland." *Quart. Journ. Geol. Soc.*, vol. xvii., 1861, pp. 133-145.)

† *Quart Journ. Geol. Soc.*, vol. lv., 1899, p. 475.

‡ "Description of the Western Islands of Scotland," 1819, vol. ii., p. 159.

Volcanic rocks of Lower Old Red Sandstone age, consisting chiefly of andesites and basalt, with insignificant sedimentary intercalations, occupy two small areas to the north of Loch Melfort and in the Island of Seil, and constitute the southern extremity, as defined by denudation, of the volcanic plateau of Lorne. The remains of what appears to be the basement conglomerate of this series are left on the Island of Lunga further to the west.

A considerable area to the south of Loch Melfort is occupied by plutonic masses of the same general epoch as the volcanic series described above, and, with their aureoles of hornfelsed schist and epidiorites, form a mass of high ground between Loch Melfort and the Barbreck River that extends westwards into the peninsula of An Cnap.

Dykes and sills of felsite, porphyrite, and lamprophyre, which by their mode of occurrence suggest a genetic connection with these plutonic masses, extend in groups or sheaves through the country rock with a general N.N.E.-S.S.W. trend, and reach their maximum development in the region between Lochs Melfort and Craignish.

North-west and south-east basalt and dolerite dykes of Tertiary age are very numerous, and, like the above, tend to run in sheaf-like groups through the area. The main group crosses Loch Melfort, where the individual dykes are so closely intruded that only a small proportion of them can be shown on the one-inch map. Another sheaf crosses the map near the head of Loch Craignish and passes through Shuna and Seil. Minor groups occur further to the south, and a few solitary dykes wander through the schist to the south of Loch Crinan.

The influence of pre-existing structures—whether foliation planes, faults, or former dykes—in modifying the course of these Tertiary dykes is even more obvious than in the case of those of Lower Old Red Sandstone age. B. N. P.

CHAPTER III.

Metamorphic Rocks.

I. Craignish and Ardrishaig Phyllites.

The distribution of the metamorphic sedimentary rocks, as set forth in the preceding Chapter, shows that the grey and green phyllites of the central belt underlie all the other schists of sedimentary origin, for the relation of the quartzite to the lower members of the series shows that the order of superposition seen in the simpler folds must be the true one; but this does not preclude the possibility of the whole group forming part of the plicated but uninverted limb of a large recumbent fold. It is probable therefore that this central belt of phyllites coincides with the core of a major fold, which throws off on either side the black slates and limestones succeeded by the quartzite.

As the rocks of this central area are most typically developed in the Craignish district, it is proposed, in the present Memoir, to distinguish them as the "Craignish Phyllites."

The description of this, the lowest group of the series, will therefore be taken first, to be followed by that of the other groups in their order of deposition. B. N. P.

I. CRAIGNISH PHYLLITES.

Craignish.—The sedimentary schists of Craignish consist of green and grey lustrous phyllites, which contain numerous thin quartzose bands. In this series there are also thin beds of finely-crystalline, whitish limestone, bands of fine grit, and compact, white quartzite.

Twenty or thirty beds of limestone, each only two or three inches thick, and separated by equally thin beds of phyllite, crop out in narrow belts, which are frequently repeated by folding on both sides of the peninsula —on the east between Craigdhu and Barbreck House; on the west between Bagh an Tigh Stoir and Bagh Dail nan Ceann. It is thought that these calcareous horizons represent the white Appin Limestone, which occurs in association with green phyllites in districts north of Oban, and they may also represent the calcareous bands in the calc-sericite schists of Perthshire.

Bands of yellowish or greenish-grey quartz-schist, which vary in thickness from an inch to 3 feet, are present in every section, and form a characteristic feature of the Craignish Phyllites. In all these quartz-schists, calcite is present as a cementing

material in varying amount, its presence being indicated by the fluted weathering and the porous surfaces of the outcrops.

Beds of yellow or white quartzite, individually seldom more than 10 feet thick, crop out along a line stretching from Barrananaoil to the islets at the head of Loch Craignish, and are again well exposed on Eilean Dubh. These quartzites consist of a fine mosaic of somewhat unequal-sized grains of quartz with some felspar and calcite, and a few scattered scales of white mica and biotite. Occasionally they contain a few small pebbles of blue quartz, but they never attain the conglomeratic character of the grits of the Kilmartin district. A peculiar limestone, which lies next to the epidiorite sill at the southern end of Eilean Mhic Chrion, may here be referred to. It is a breccia, consisting of angular pieces of white marble in a dull greenish-grey limestone matrix. It resembles a limestone-breccia from the Gravellachs (p. 32), and may really belong to the same horizon. Passing underneath the limestone and epidiorite is a mass of honey-combed and rather coarse-grained quartzite. The presence of partly-dissolved fragments of limestone suggests that some of the holes are due to the solution of inclusions of calcareous rocks, whilst other holes are like flattened tubes, and seem to have been filled with a greenish calcareous mud. The quartzite is underlain by greyish phyllites of the usual kind.

Large quartz-veins are almost wanting in the Craignish phyllites, but small veins and strings, which generally run with the strike of the beds, are locally abundant. They frequently contain nests of dark green vermicular chlorite, which has doubtless been derived from the phyllites. These veins are cut by the dykes of Old Red Sandstone and Tertiary age, and are probably segregation-veins formed during the later stages of metamorphism of the district.

It is impossible to give any sort of estimate of the thickness of the phyllites, but it is evident from a consideration of the repetition by folding of the epidiorite sill on Mullach Dubh, and again on Clach Bharr, that a small thickness of phyllites occupies a very broad area.

Owing to the presence of the quartzose and calcareous bands the bedding is easily determinable, and hence also the character of the folding. The latter is of an asymmetrical type, and is not strictly isoclinal. (Fig. 3, page 16.) The eastern limb of each anticline is relatively long and dips at moderate angles (usually between 30° and 50°) to the E.S.E., whilst the short western limb is inclined at a high angle, and in the majority of cases is slightly inverted. The folds often have a gentle pitch to the S.S.W., a particularly clear instance involving an epidiorite sill being seen three-quarters of a mile east of Ardfern.

Apart from jointing, the fissile character of the phyllites is due partly to a strain-slip-cleavage and partly to an earlier structure of the nature of true slaty cleavage. The latter structure is marked by an elongation of the minute quartz-grains

and an orientation of the mica and chlorite scales. The cleavage-planes are inclined in the phyllites to the E.S.E. at an angle which varies between 40° and 50° on the east side of Craignish, whilst on the west coast the average dip is slightly lower (30° to 40°). Thus the cleavage-planes lie more or less parallel to the axial planes of the folds.

The compression which has caused the slaty cleavage in the phyllites has contorted the calcareous beds into a series of numerous short, tightly-packed folds, whose axial planes lie in the plane of the cleavage. (See Fig. 1.) The limestone itself, however, does not show any signs of cleavage.

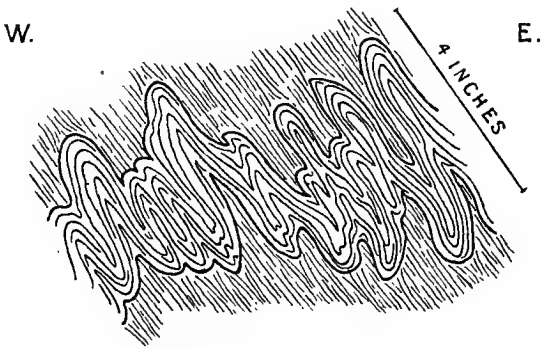


Fig. 1.—Contorted Limestone in Phyllites.

The quartz-schist bands have usually not been puckered like the limestone beds, but are traversed by a set of cleavage-planes which are actually open joints spaced at short distances apart. The cleavage, as it passes from phyllite through a quartzite band into phyllite again, is bent out of its course in the quartzite, and in the most frequent case takes on a direction more nearly perpendicular to the stratification.*

The slaty cleavage is crossed and its planes are wrinkled and folded by a strain-slip-cleavage, the gliding planes of which are oblique to the first cleavage. The accompanying figure (Fig. 2) shows how the mica-scales in the neighbourhood of a gliding plane (a, b) have been bent out of their original direction, which was parallel to the first cleavage. The minute fold has often become a fault, along which one lamina of schist has moved relatively to its neighbour, the direction of motion being proved by the direction of bending of the mica-scales on opposite sides of the gliding plane.

The strain-slip-cleavage, unlike the slaty cleavage, is not universally present even in the argillaceous rocks, but no general statement defining its distribution can be given.

* The rules governing the deflection of cleavage in passing through beds of different lithological character are discussed by Mr. Harker in the *British Association Report for 1885*, "On Slaty Cleavage and Allied Rock-Structures, with special reference to the Mechanical Theories of their Origin," p. 829.

Whilst it is most strongly developed in those argillaceous rocks which possess a good slaty cleavage, it does not always follow a particular bed throughout even a small fold.

The gliding planes are spaced at intervals of $\frac{1}{100}$th to $\frac{1}{50}$th of an inch apart, and dip in one of two directions. In the most frequent case the gliding planes are nearly vertical in the phyllites, as shown in Plate II., and the direction of the shear is such that the more easterly lamina of schist has moved downwards against its western neighbour. The strike of the planes is not quite parallel to the strike of the folding and cleavage, but takes a direction about N.10°E. Just as the slaty cleavage of the phyllites is represented in the quartzite bands by fissures spaced at finite distances apart, so the closely-arranged gliding planes of the strain-slip-cleavage are represented by more distant fissures in the quartzose beds.

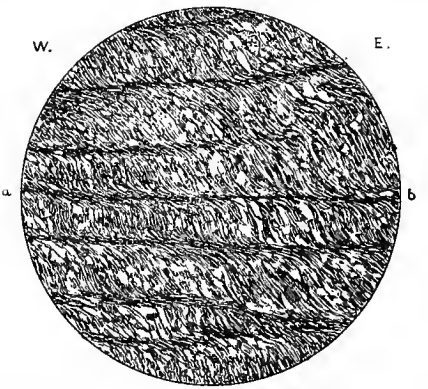


Fig. 2.—Strain-slip-cleavage in Phyllites. × 20.

Plate II. also shows how the gliding planes are deflected in the harder beds and pass through the latter along the fissures due in all probability to the earlier cleavage. If the fissures in the harder beds be spaced, as indeed they are, about an inch apart, it will be readily understood that they must have carried the combined displacement due to fifty or a hundred gliding planes in the phyllites. Hence appreciable movement has taken place along the fissures in the harder beds, which have thus been sliced up into lenticles.

The contorted limestone beds are also sheared along planes which pass through the drawn-out limbs of the folds. The phyllitic material, which at first formed the cores of neighbouring anticline and syncline, has become continuous, whilst the limestone is separated into rows of isolated lenticles, as shown by the central band of Plate II. Pseudo-conglomerates of this nature were readily formed from the hard layers, which had previously been bent into short, tightly-packed folds.

Referring to Fig. 2, it will be seen that there is no appreciable foliation parallel to the original slaty cleavage, but that there

is a slight foliation parallel to the strain-slip-cleavage. It is marked by the predominance of mica in the neighbourhood of the planes of strain-slip-cleavage, whilst quartz and felspar are relatively more abundant in the intervening spaces.

In the second mode of occurrence the gliding planes are horizontal or inclined at low angles (up to 20°) towards the west. In such cases the strain-slip-cleavage has a definite relation to the folds, since it is limited to the neighbourhood of the arch or trough of a fold and dies out on the limbs. Further, the deflection of the mica-scales shows that the shearing motion has taken place by each lamina of schist moving over the lamina beneath it towards the west, *i.e*, in the same direction as the folds are reclined (see Fig. 2). This relation, which holds good not only in the phyllites of Craignish, but also in the black slates of Easdale and Luing, can scarcely be fortuitous, but points to a common origin for the strain-slip-cleavage, cleavage, and folding in one period of earth-stress.

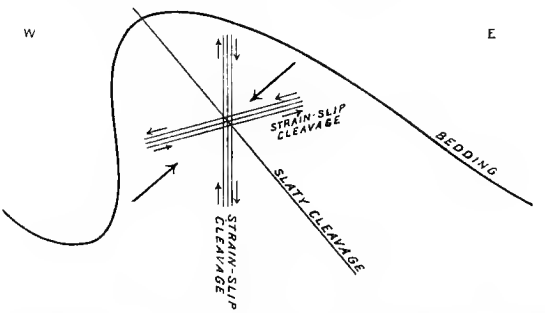


FIG. 3.—Showing relations subsisting between folding, slaty cleavage, and strain-slip-cleavage.

Fig. 3 shows in a diagrammatic way the relations which subsist between the rock-structures described above. It will be noticed that the two directions taken by the strain-slip-cleavage are roughly at angles of 45° to the planes of slaty cleavage. As the slaty cleavage is normal to the direction of maximum pressure,* there is a curious coincidence between the directions of the planes of strain-slip-cleavage and the planes of maximum tangential stress due to the same set of forces. Slipping has taken place along them in both cases in the direction which such stresses would have led to. If this is more than a coincidence it would point to there being two sorts of cleavage, both illustrated in the rocks of the district, but quite different in their method of origin.

An important factor, which conditioned the change in the mode of deformation, viz., from slaty cleavage to strain-slip-cleavage, is a greater rigidity of the phyllites, or rather a loss of capacity to flow. The change might be brought about by denudation of the area bringing the rocks nearer to the surface.

* Harker, "Report on Slaty Cleavage," *Brit. Assoc. Report* for 1885.

Pseudo-conglomerate in Phyllites on shore west of Gemmil, Craignish (looking south). Strain-slip-cleavage in nearly vertical lines, which flatten on passing through harder beds; cleavage, which dips at low angles from right to left, is best seen at foot of section (p. 15).

But it is almost certain that this would alter the direction of tilt of the maximum pressure, a case which seems forbidden under the above-mentioned conditions. If, however, during the production of the older cleavage, the pressure was so rapidly increased that the plasticity of the rock-mass was not sufficient to permit the gradual and continuous distortion which results in slaty cleavage, an adjustment might take place by closely-spaced faults or fold-faults lying diagonally to the direction of greatest compression. Further, the same change might be brought about if the production of the slaty cleavage with the accompanying development of and recrystallisation of minerals stiffened the phyllites to forces acting in a direction perpendicular to the cleavage. In that case any continuation of the pressure beyond a certain point would cause the rocks to fracture rather than to flow.

According to either of these views, the strain-slip-cleavage, the cleavage, and the folding are recognised as concomitant, though not simultaneous, effects of the same lateral pressure, and do not necessitate two or more distinct periods of earth-stress in the district. It should be pointed out, however, that a slight veering of the direction of maximum pressure towards the close of the period of earth-stress is required to account for the slight difference in strike between the strain-slip-cleavage and the other structures. H. B. M.

These rocks—with the exception of the limestone—and structures are continued into the southern end of the promontory, the outcrops of green and grey phyllites making up the greater part of the area. The whitish or yellow and rusty weathering calcareous quartzite-bands, much repeated by folding, form a belt along the eastern shore and pass out to sea before the point is reached. As in the case further to the north, the grits have yielded less to the stresses than the associated argillaceous sediments. The original pebbles of blue quartz are still well defined, especially where a calcareous cement is present, which seems to have flowed and thus allowed deformation without fracture or granulitisation of the larger pebbles. On the western shore near Craignish Point the phyllites are intimately intercalated with thin bands of greenish quartzite. Rocks of this latter type pass southwards into the islands south of Craignish Point, and the sedimentary schists on Reis Mhic Phaidean, an islet further to the west, also belong to this group.

Asknish and Kilmelfort.—The Craignish phyllites with their accompanying thin bands of quartzite and white limestone are continued northwards into the ground lying between Craignish and Loch Melfort, but assume the hornfels type of alteration as they approach the plutonic masses by which they there become invaded. This alteration occurs in an irregular and sporadic manner, and sometimes even where no igneous rock is visible at the surface. The limestones and quartzites are recognisable along the east side of the belt, the former being transformed

into calc-silicates and white marble, which has been wrought to the east of Kilmelfort. These rocks are also found near the extreme west of the belt in the promontory of Asknish. The quartzite is there well developed and rises in a small cliff above the main road, where it bends to the east at Asknish, while the marbled limestone is well seen on the shore at Loch Melfort on the north side of the granite mass of An Cnap. The distribution of the phyllites and epidiorite intrusions in the intermediate ground suggests that the rocks, as well as being repeated by rapid corrugations, are here arranged in a major anticline.

On the north side of Loch Melfort the rocks of the group resume their normal character, the arrangement of the minor and major folds being similar to that found in Craignish and on the south side of the loch. Near the head of the loch and close to the Old Powder Mills at Melfort House the white limestone was once extensively quarried, and the quartzites are also seen in the immediate neighbourhood. Westwards for a mile or so the coast section reveals the phyllites invaded by one or more sills of coarse-grained epidiorite, which are repeated several times by folds. On the shores of Kilchoan Bay the limestones and quartzites of Asknish make their appearance, and, with constant repetitions, occupy the ground westward to the Point of Degnish, where this series gives place to the dark schists and limestones of the overlying groups.

Shuna Island.—About two-thirds of this island are made up of rocks belonging to the Craignish phyllite group, all the members being more or less represented. The structure of the island may be looked upon as a continuation of the western limb of the major fold which occupies the northern shore of Kilchoan Bay and Degnish Point. Near the western side of the island a single sill of epidiorite is found invading the grey and green silky phyllites. Passing eastwards, there is an excellent section exposed along the southern shore, in which the phyllites with thin calcareous and quartzose bands are repeated by minor folds. The rocks have everywhere been much affected by strain-slip-cleavage, with the effect that sigmoid fragments of the harder bands have been isolated and arranged in rows among the more pelitic material. The folds are for the most part isoclinal, and the dip of the axial planes constantly to the east. Towards the eastern limit of the belt the white limestone and quartzite bands make up an appreciable proportion of the rocks of the group. The grey and green phyllites can here be traced up to within a few feet of the dark flaggy limestones of the overlying group, so that if the dark slates are present they can be of no great thickness. Along the north coast the dark slates certainly intervene between the grey phyllites and the first limestone outcrop, black slates having been worked in this locality. B. N. P.

Islands in Loch Craignish.—Passing eastwards to the chain of islands on the east side of Loch Craignish, we find green and

grey phyllites with calcareous sandy ribs lying in stripes between the sills of epidiorite along the western shores of Eilean Righ, Eilean nan Gabhar, and Eilean Macaskin. The white limestone runs through the centre of the most northerly of the group and occupies a considerable area on the east side of Eilean Macaskin, where it was at one time wrought for lime.

J. S. G. W.

Kilmartin.—In the more complex area which lies beyond the belt of quartzite east of the head of Loch Craignish, grey phyllites of this group are found to underlie black slates and limestones in the deeper exposures. These rocks are fully described in the sequel, when dealing with the higher groups and the structure in which they are involved. As we follow these folds to the S.S.W. it is found that, owing partly to the effect of pitch, and perhaps still more to that of a combination of a general lowering of the surface-elevation with the development of a very gentle major anticline, the grey phyllites enter more and more into the mesh-work of sedimentary rocks and epidiorite masses, until in the neighbourhood of Poltalloch they occupy a considerable area of the surface. They are here associated with a light-coloured coarse epidiorite very different in texture from the fine-grained slaggy rock which usually occurs with the surrounding black and pebbly limestones.

Isolated exposures of these limestones protrude through the raised-beach deposits and peat of the Moine Mhôr, which bounds the area on the east and south.

The white limestone and other calcareous beds of the upper part of this group appear on the coast at Duntroon Castle, where the more impure bands are altered into calc-silicate-hornfels, and the limestones marbled, against a massive coarse-grained epidiorite sill.

In a small cliff section close to this point the sandy phyllites lying between two lines of crush have retained their original bedding-planes in a marked manner, the foliation-planes being parallel to the lines of dislocation. The bedding-planes can indeed be generally detected in the rocks along this coast-line, the grade of metamorphism being nowhere high.

Grey phyllites also occur in the folds which bring up the black slate and limestone in the Dunardry region south-west of Cairnbaan, on the Crinan Canal. B. N. P., J. S. G. W.

II. ARDRISHAIG PHYLLITES.

For a detailed description of the lithological characters of the Ardrishaig phyllites, a small area of which enters into the extreme south-east corner of this Sheet, the reader is referred to the account of these rocks in the Explanation to Sheet 37 of the Geological Survey, p. 32.

Comparison of this description with that given at an earlier page of this chapter will show that it will apply, in almost every respect, to the phyllites of the Craignish district. This close

resemblance in lithological character between the rocks of Craignish and the Ardrishaig phyllites has been already pointed out,* and, as stated in Chapter II., the mapping of the present area has afforded strong presumptive evidence for this correlation.

The Ardrishaig phyllites in this district are confined to a very small area south of the Crinan Canal at the extreme south-east corner of the Sheet. They are very well exposed in the Craig Glass Burn, the lower portion of which has carved a long and narrow gorge in the easily-eroded phyllites. Instead of the more typical green colour, they occur here as bluish calcareous phyllites intermixed with quartz-schist and quartzose mica-schists. They are succeeded on their western boundary by the coarse basal grit of the Lochawe group, and have been invaded by sill-like intrusions of epidiorite. The limestone and black slate, both of which almost invariably intervene between the Lochawe grit and Ardrishaig phyllites in the area lying to the north of the Canal, are here practically unrepresented, the former being altogether absent and the latter reduced to insignificant proportions. J. B. H.

II. Easdale Slate and Limestone Group.

(a) *Degnish, Shuna, Reisa an t-Sruith.*—As already stated, the passage from the Craignish phyllites into the black slates of this group is well seen in Degnish on the mainland and on the western shores of Shuna, where the latter consist of black and grey slates with a few intercalations of dark micaceous limestone and some white sandy layers. The series is highly folded. The black slates pass by intercalation into a series of limestones. Near the junction the latter occur in dark blue flaggy and micaceous layers, resembling the thinner isolated beds in the slates. These are succeeded by more massive beds of mottled limestones, the mottling being due to aggregates of dark, almost black, cleavable calcspar set in a lighter grey granular calcareous matrix. The appearance of the rock suggests an oolitic origin for the dark spots. Some of the layers are grey and very siliceous and suggest a cherty origin, the chert having been converted into crystalline silica and subsequently traversed by vein quartz. A honeycombed skeleton of such a rock from which the calcite has been weathered out is found on the shore to the south of Shuna House, and also occurs on a separate fold to the north of the pier. Sandy calcareous beds are associated with the mottled limestone near the north of the island. In the Degnish outcrop, which skirts the western shore of the promontory, the mottled limestone, which has here been quarried for lime, is the furthest west and presumably the highest member seen. On the Island of Shuna there is no means of determining clearly which is the

* J. B. Hill "On Progressive Metamorphism in the Region of Loch Awe." *Quart. Jour. Geol. Soc.*, vol. lv., 1899, p. 475.

uppermost member of the group, as the limestone is evidently nearly as much plicated as the associated slates, the two rocks being intimately interfolded near the northern extremity of the outcrop. At the widest part of the Shuna outcrop the mottled limestone is exposed in rocky clints surrounding and inosculating with areas of limestone and dark slates in great complexity. As one passes westwards the mottled limestones are the first to disappear, and dark flaggy limestone alternates with slates, until slates are the last rocks encountered on the most westerly point of the shore. Whether the alternation is due to folding, and the western outcrops of dark slates and limestones are the reappearance of those to the east, or whether the phenomena indicate an upward succession from east to west, is therefore left doubtful; but the appearances at the north end of the outcrop somewhat favour the former view. If this be so, this belt of limestone must occupy the core of a compound syncline whose axis stretches from Degnish through Shuna and Reisa an-t-Sruith in the Sound of Jura, where the dark and mottled limestones are quite recognisable. A circumstance which also favours this explanation is the association of the flaggy dark limestones alone with the black slates to the west; while on the mainland in the Kilmartin area the mottled limestone has been found to overlie the dark limestones. The sandy beds which overlie the mottled limestone in Shuna may even belong to the basement members of the quartzite group.

Adopting the hypothesis that the Degnish and Shuna limestone lies in the centre of a fold, it follows that the black slates of the western belt must represent the reappearance of those which occupy the narrow space between the Craignish phyllites and the limestone on Shuna.

(b) *Easdale, Seil, Luing, Torsay, Belnahua, and Smaller Islets.*—This group of islands is almost entirely constituted of black slates with thin but very characteristic dark limestones, and a few thin stripes of quartzite, together with one main outcrop of the epidiorite. They have long been noted for the roofing slates afforded by the slaty members of the group. Throughout these islands the state of metamorphism is very low, and the bedding planes are almost everywhere easily recognisable. The strata are often disposed in gentle undulating folds, dipping towards the east and accompanied by overfolding towards the west, while the cleavage-planes dip persistently eastwards.

Easdale.—In this small island the black slates are extensively quarried to a considerable depth below sea-level. (Plates I. and VII.) The rocks are much overfolded towards the west, and the cleavage is at a high angle. The nature of the overfolding has long been known to the working managers, and Gaelic names are applied to the different limbs of the folds and are well understood by the quarrymen. Further reference to this is made in the Chapter relating to Economics.

Seil.—On the north side of the narrow sound which separates Easdale from Seil the slates were formerly wrought under condi-

tions similar to those now found on the former island. The sea has, however, broken into the quarries and stopped the working.

Southwards along the shore the thin dark limestones are constantly repeated by folds, but with an apparently slightly ascending succession, as far as the great sill of epidiorite. This igneous mass seems to occupy a compound syncline, for at Balvicar bands of slate, recognised by the quarrymen as the same as those at Easdale, are extensively quarried, with the same methods of working a similar system of steep overfolds.

Luing and Torsay.—The much-plicated black slates and limestones of Seil are continued into these islands and exposed all round their coasts, as well as on the small islets off the west coast of Luing. The type of folding is for the most part shallow and undulating; the longer axes of the folds run nearly north and south, and the steep sides of the folds face to the west. Occasional overfolding is also seen. The structure is admirably displayed near the steamer-landing at Black Mill Bay, on the west coast of Luing. No great thickness of strata appears to be involved, for the same bands of limestone are repeated again and again in the coast sections round the south end of the island between Black Mill Bay and Toberonochy. Slates have been worked in almost every part of Luing, the principal quarries being situated at Port Mary and Cullipool in the northern part of the island, and at Toberonochy on the east coast.

The Seil epidiorite sill is continued through Torsay into Luing, and probably occupies a continuation of the same compound synclinal fold.

Belnahua.—On this small island the slates have been so long worked that the island is now but a thin outer shell of the black slates, just sufficient to keep out the sea from the great quarryings which occupy the greater part of the area, and reach a depth of over 90 feet. Several bands of different qualities are wrought in the same working-face, with thin intercalations of bluish or black limestone separating some of the bands. The aggregate thickness of rock wrought may amount to 60-70 feet. The same system of folding and cleavage as that found on Luing prevails. Black slates of good quality and limestone bands in gentle undulating folds are seen all round the shores of Fladda, the islet on which the lighthouse at the north end of the Sound of Luing is situated.

(c) *Lunga, Scarba, and Jura.*—The members of this group, in which black slates preponderate, form a fringe along the eastern shores of the two former of these islands, and are probably continued in the projecting ledge which extends for a mile on each side of Kinuachdrach Harbour, near the north end of Jura. The black slates are associated on one side with grey phyllites which, as already suggested, may represent an upfold of the Craignish phyllite, and on the other are certainly intercalated with bands of quartzites, some of which are pebbly and calcareous, while one band is dark-coloured from the amount of

carbonaceous matter which it contains. The same system of undulating folds and occasional overfolding, already described in Luing and Easdale, is everywhere to be observed. The remarkable relations between the Easdale group and the quartzite group in these islands will be discussed in the sequel.

(d) *Mainland East of Craignish.*—The occurrence of a small patch of slate and limestone near Turnalt, on the west side of the Barbreck River, has already been referred to, when attention was called to its importance in defining the relations of the group to the phyllites of Craignish, especially in comparison with the succession in Shuna. West from Turnalt some small lenticular areas of black schist, too small to show on the map, occur among the phyllites, and are doubtless outliers from this outcrop. The altered limestone to the north, which has been quarried along two successive outcrops, is probably the continuation of the Turnalt band, although its characters, as well as those of the associated argillaceous beds, have been so much altered by the diorite of Tom Soilleir as to render exact comparison difficult. For a similar reason, and also on account of the great extent to which the rocks are invaded by sills of epidiorite and covered by later rocks, the position of the black slate and limestone group to the east of Kilmelfort is difficult to locate, though altered black slates and limestones with outliers of quartzite occur along the edge of the Sheet.

Kilmartin.—Returning to the area east of the head of Loch Craignish and the Barbreck River, the observer finds, after crossing the belt of quartzite already mentioned, that the black slates and black limestone constitute a large part of the meshwork of sedimentary material which encloses the larger outcrops of epidiorite and quartzite. In the numerous folds that extend in a S.S.W. direction from the edge of the map east of the Barbreck River to the head of Loch Crinan, the relation of the dark slates and limestones to the quartzites on the one hand, and to the grey phyllites of Craignish on the other, is often clearly shown, and can be expressed in descending order as follows:—

d. Quartzite and pebbly grit . . .	Quartzite Group.
c. Dark pebbly and conglomeratic limestones	
b. Dark slates with intercalations of dark limestones	Easdale Group.
a. Grey phyllites	Craignish Phyllites.

The stratigraphical relation of the groups and the nature of the folding is more fully discussed in the sequel dealing with the quartzite group, where a horizontal section across the area is given. B. N. P.

Good sections of the black slates are exposed at various points along the hill road between Upper Largie and Old Poltalloch, The limestone also appears in several of these sections, and in one outcrop the rock contains dark calcite masses similar to those of Degnish and Shuna. Several of these outcrops are

overlain by the dark pebbly limestone (*c.*) containing fragments of the subjacent black slates and limestone. In both branches of the stream which flows past Slochavullin the strata of zone *b.* are well displayed, the black flaggy limestone being sometimes exposed within the cores of folds of the pebbly limestone. Rocks of the same zone crop out along a fold which stretches from the south of the Barr Mor to beyond Garbh Shron.

Dark slates and flaggy limestone are also visible in the quarries at the roadside south of the village of Kilmartin, and are interfolded on the southern slopes of Barr Sailleach and to the north of Carnassarie.

The passage of grey phyllites of Craignish type (*a.*) into the black slates is well seen in the valley on the east side of Barr Mòr, north of Kilmartin, and can also be studied in exposures to the north of Poltalloch House.

Dark crystalline limestone accompanied by dark phyllites occurs along the eastern shores of Eilean Righ and Eilean Macaskin in Loch Craignish. J. S. G. W.

Cairnbaan and Dunardry District.—In the area stretching southwards from the River Add to the margin of the Sheet, the black slates are found on both sides of the Crinan Canal. On the north side, near Cairnbaan, two folds of the slates are separated by a mass of epidiorite, the sedimentary rocks that flank them on either side belonging to the quartzite group. The slates of the eastern band, which contain at least one subsidiary band of black limestone, have been extensively worked.

The axial planes of the folds in this area dip towards the north-west, the cleavage-planes being more or less parallel to these planes with a dip of 50°, while the long axes of the folds run N.N.E. and S.S.W.

South of the Canal the slates and limestone are found in a compound fold on Dunardry. They are folded and cleaved in a similar manner to that just described, and extend in a S.S.W. direction to the edge of the map.

The black slates have been extensively quarried on both sides of Dunardry, the largest openings being on the south side, where the slates are traversed by a thin band of highly-cleaved vesicular epidiorite. The relations of the dark flaggy limestone to the overlying dark pebbly limestone are admirably shown on both sides of these folds, the latter being evidently the younger rock.

Outliers of the pebbly rock are also frequent within the fold, the junction with the subjacent black flaggy limestone being a discordant one. The pebbly limestone throughout this area is succeeded by a conspicuous band of coarse epidiorite, which in turn is flanked on its outer margin by the pebbly quartzite.

Near the southern end of the outcrop, on the shores of Loch Fada, grey phyllites of Craignish type emerge from beneath the black slates, as in the Kilmartin area.

On the west side of the Dunardry outcrop, the rocks of the overlying quartzite group with their accompanying sills of

epidiorite occupy the surface; but on the eastern shore of Caol Scotnish, a branch of Loch Sween which just enters the map, the black slates and thin limestones of this group again appear, and are overlain by a dark pebbly limestone. A little to the north of this outcrop the quartzite opens out on the side of the hill and exposes the top of an anticline of the underlying black slates, surrounded by a dark calcareous gritty conglomerate.

B. N. P.

District between Dunardry and Creag Ghlas.—These rocks which succeed the Ardrishaig phyllites form a portion of the Loch Awe group that were first described by Mr. Hill in 1899,* and later in the Memoir of the adjoining Sheet (37).† It will be seen that in the present Memoir a more detailed scheme of grouping has been adopted, and that the members of the Loch Awe group have been described under their individual sub-divisions.

The limestone is usually blue in colour, but varies from lighter tints to very dark blue and sometimes blackish hues. It is crystalline and stratified, generally very thin bedded, and often foliated with mica developed along the planes of schistosity. Shading into slates on the one hand and into grits on the other it presents impure types ranging in their composition in proportion to the amounts of argillaceous or siliceous material with which it has been mixed. With argillaceous matter sufficiently in excess it passes into calcareous slate, and difficulty has been experienced in differentiating such impure limestones. There is a like transition from limestone to grit, the former being often thickly charged with pebbles of quartz and felspar. The limestone is, moreover, frequently of a fine sandy type, and in this condition is strongly represented where it lies immediately on the Ardrishaig phyllites. This has been especially noted and described in the Memoir of the adjoining Sheet (37) along the boundary of the Ardrishaig and Loch Awe groups between the Crinan Canal and Glen Aray. In this condition tiny laminations of sandy material pervade the limestone in such a way as to leave no doubt of their being a phase of the original limestone deposit. The limestone is frequently coarsely crystalline, but is in many instances of a fine granular or cherty type, and this is especially the case when associated with much black slate. All the various types may be met with in the same seam: slaty limestone, compact fine-grained, and the coarse gritty type with pebbles as large as an inch, succeeding one another in unbroken continuity. It must be understood, therefore, notwithstanding the fact that the pebbly limestone in this Memoir is specially treated with the pebbly quartzite, that in the area now being described it cannot be differentiated from the finer-grained limestones.

The slates may readily be distinguished from the Ardrishaig phyllites. In their typical condition they range in colour from dark blue to black, while occasionally they contain sufficient

* *Q.J.G.S.*, vol. lv., pp. 470-493.

† "Geology of Mid-Argyll," pp. 40-56.

graphite to soil the fingers. They are more homogeneous, harder and more massive than the Ardrishaig phyllites, and contain much less lime. While these dark slates are undoubtedly the characteristic type, paler varieties sometimes occur ranging from grey to brown. Over the Loch Awe group generally chlorite is rare; occasionally, however, both the slates and grits are green, and the clay slates can then only be distinguished from the Ardrishaig phyllites by their lithological characters. The green varieties, however, are only of local occurrence, and do not occupy a definite horizon. Although the slates are frequently highly contorted, the cleavage is often perfectly regular, and they have been wrought for roofing slate.

The slates are often intermixed with siliceous material, and gradually pass lithologically into grits. Not only is there a gradual passage into the siliceous members of the Loch Awe group, but these latter, even in their greatest development, are separated by argillaceous bands precisely similar to the main body of the slates, and this holds good whether the slates are green or of the more general dark blue or black type. Occasionally the slate bands enclose pebbles of quartz and felspar, some of which are as large as those in the coarsest grit bands, or gritty limestones; but on the whole they are of far rarer occurrence than in the calcareous beds.

In the area south of the Crinan Canal situated between the Dunardry burn and the boundary of the Ardrishaig phyllites the slates and limestones are of limited distribution as compared with the more siliceous members of the Loch Awe group with which they are associated. Along the hollow watered by the Dunardry burn two bands of limestone are seen associated with dark slate. Both seams are of the pebbly type, but in the easterly band normal limestone also occurs together with a little dark slate. On the eastern side of the Carndubh burn are thin seams of sandy limestone with rusty friable weathering, and in the lower portion of the same stream, blue and black slates, thin calcareous and grit bands are closely associated. Further east limestone is rare, but dark slate sometimes divides the grit bands. The limbs of the isoclinal folds and the foliation are both inclined steeply to the north-west.

The slates and limestones of this group that lie to the east and north of Kilmartin Glen have been described under the next heading with the quartzites and pebbly limestones. J. B. H.

Glen Sabhail and Ardnackaig.—Slates belonging to this group occur in two narrow belts—one in Glen Sabhail (3 miles S.S.W. of Crinan Harbour), and the other on the erosion platform of the 100-foot beach at Ardnackaig (west of Glen Sabhail). In Glen Sabhail they are seen for about a third of a mile, and possibly have a larger extent, much of the bottom of the Glen being covered with alluvium. In both localities the typical features of the Easdale slates are displayed, and no doubt can be entertained with regard to their position. They are soft black lustrous slates, with bands of the thin blue-black lime-

stone which forms so constant a characteristic of the Easdale group, and often greatly assists in the recognition of the group. Owing to their purity they are frequently wrought for lime, as was the case in Glen Sabhail before the desertion of the old village. It is interesting to note how fertility follows the horizon wherever it occurs.

The chief interest of these small exposures consists in the light which they throw upon the sequence of zones in the quartzite series next to be described. Other small outcrops of black slate indeed occur, such as those seen near the roadside to the west of Caol Scotnish, but appear to be interbedded with the quartzites, and may be considered as part of that series.

E. B. B.

CHAPTER IV.

Metamorphic Rocks—*Continued.*

III. QUARTZITE GROUP.

As already mentioned, the rocks of this group occupy two separate and distinct areas. The western belt (A) includes the islands to the west of the Sound of Jura; the eastern area (B) occupies part of the mainland lying to the east and south of Loch Craignish.

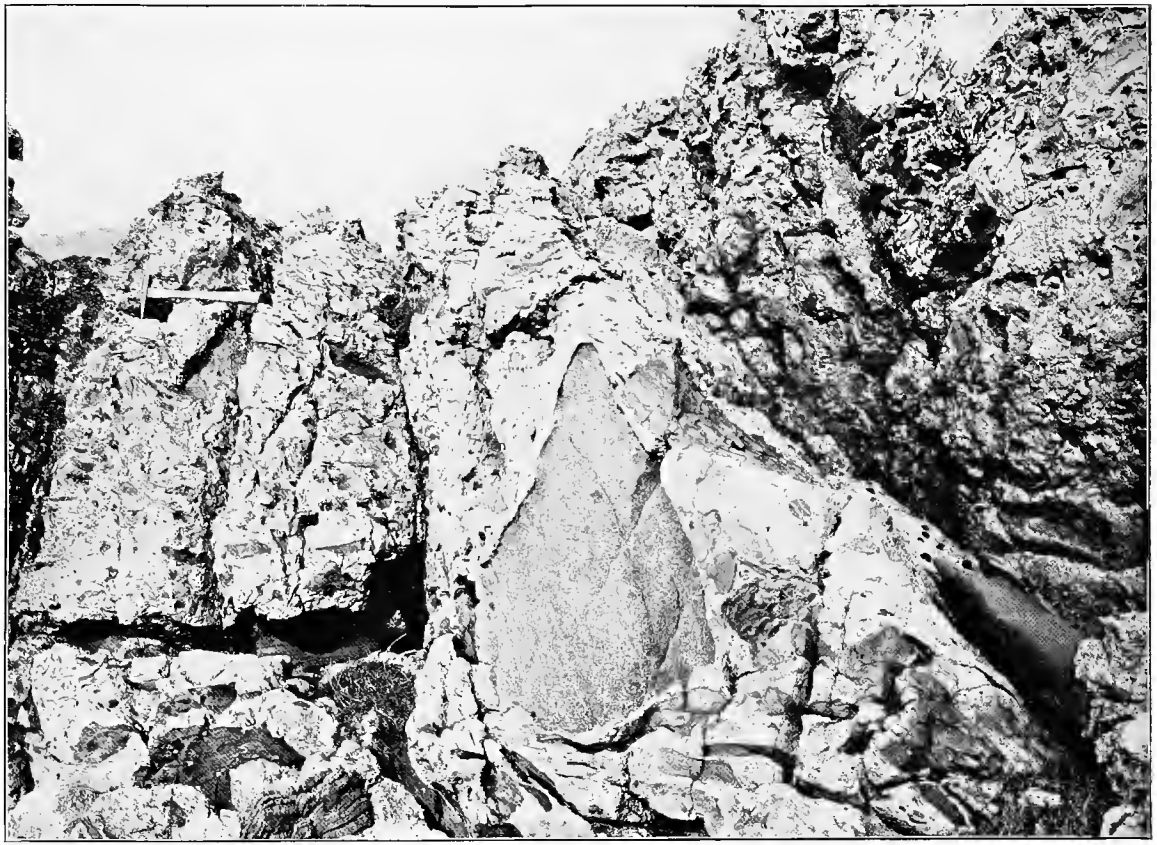
Western Islands.

(A) The succession determined in the Island of Scarba, which occupies a central position in the quartzite belt, may be taken as typical of the whole area, although local peculiaritites are met with which will require separate attention.

Scarba and Lunga.—The zone of quartzite in contact with the members of the Easdale slate group on the east side of the island is often conglomeratic, and contains large fragments of the local rocks of that group. (Plate III.) It appears certain that we are here dealing with a basement conglomerate, and therefore the various lithological groups encountered in crossing the quartzite belt from east to west must, apart from repetition, represent an ascending sequence. No important repetition having been detected, the following is a tabulation of the zones in descending order, being exactly the opposite to the order which they present in the traverse:—

5. Flaggy calcareous shales and sandy beds, some of which contain flattened worm-casts, the so-called "fucoids" of older palæontologists. The surfaces of the shales are sometimes covered with matted masses of these casts.
4. White and yellow fine-grained quartzite with small rounded concretions on the weathered surfaces simulating the so-called "pipes."
3. Coarse false-bedded whitish- and pink-coloured quartzite in massive beds, containing well-rounded pebbles of pink felspar and blue quartz.
2. Flaggy quartzites with thin phyllitic partings; sandy calcareous flags and slates with worm-casts ("fucoids") and occasional thin, sandy, rusty-weathering dolomitic limestone bands.
1. Pebbly quartzite with blue quartz and cleavable felspar grains, passing locally into a coarse boulder-bed full of fragments of black slate, black flaggy limestone, calcareous grits, and quartzite, the largest of the included blocks reaching a length of over seven feet.*

*Compare this section with that occurring on the east side of Islay, between Portaskaig and Bonahaven. "Geology of Islay," *Mem. of Geol. Survey*, 1907, p. 48.



"Boulder Bed" on shore, $\frac{3}{4}$-mile N.N.W. of Kilmory Lodge, Scarba (p. 28).

The main junction between Groups 1 and 2 in Scarba, Lunga, and Eilean Dubh Mor is a faulted one; but in Lunga, to the east of the fault, members of the two groups occur folded together in natural sequence, so that the fault does not seriously interfere with the reading of the sequence.

The basement conglomerate of Zone 1 and its relation to the Easdale slates is well seen on both the north and south coasts of Scarba, as well as at several intermediate localities. The coarser conglomerates have generally a gritty and somewhat calcareous matrix containing abundance of pebbles of quartz and felspar. The striking feature of the deposit is the large size of the included blocks. (Plate III.) These conglomeratic beds merely form part of a series containing numerous intercalations of pebbly quartzite. Attention has already been drawn to the fact that the Easdale slates, as developed in Scarba, contain numerous interbedded bands of pebbly quartzite of similar type to that occurring with the boulder-bed, and although the former are abundantly represented in the boulders of the conglomerate, their presence suggests that the line of erosion, marked though it be in character, may not represent a break of prime importance in the stratigraphy.

The boulder-bed in Lunga is in every way comparable with that of Scarba.

Zone 2 can be followed through Scarba and Lunga into Eilean Dubh Mor, but in none of these islands is the whole succession shown owing to the above-mentioned fault. It can also be recognised in the Garvellachs, as will be shown in the sequel.

Zone 3 can be traced from Scarba through Guirasdeal, Lunga, and Eilean Dubh Mor to Eilean Dubh Beag and the Garvellachs. In Eilean Dubh Mor the pebbles in some members of the zone measure as much as 2-3 inches in diameter. They are well rounded, and consist of jasper, quartzite, hardened slate, and felsite; but no granite pebbles have been observed. Conglomeratic bands, probably on the same horizon, also occur on the west coast of Jura.

Zone 4.—This zone, with its pseudo-pipes, forms a belt along the western shore of Scarba. It is probably continued south into Jura, but has not been recognised on the islands north of Scarba.

Zone 5.—The shales and flags of this zone are restricted on Scarba to Sgeir nan Gabhar, a small skerry off the north-west coast. The matted worm-casts stand out in bold relief on the gently-sloping surfaces of the flags, laid bare at low water, when the skerry is connected with the main island. This zone has also been recognised on the north-west coast of Jura.

Jura.—In the portion of Jura represented in the present sheet the same persistent dip towards the east obtains throughout the area occupied by the members of the quartzite group. Although the zones established on Scarba have not been traced through the northern part of Jura, some of them at least have, as shown above, been recognised in the latter island.

A small isolated outcrop of a boulder-bed on the north-east coast of Jura, a little to the north of Rudh' an Truisealaich, is thus described by Mr. Wilkinson*:—"The matrix of this conglomerate is highly calcareous and contains pebbles and lenticular masses of various rocks, consisting of blue, violet, and white quartz, limestone, felspar, grit, and possibly granite. Underneath these fragmentary beds lie flaggy quartzose grits and highly-puckered slates with thin quartzose bands." The outcrop is isolated from the main mass of the quartzite, but may be an outlier of the basement conglomerate of the latter formation. In fact, there is a strong presumption that the fault that passes northwards through Scarba, Lunga, and Eilean Mor is continued southwards through this part of Jura, and forms the boundary between the main belt of the quartzite and the phyllitic rocks of the Easdale slate and Craignish phyllite group of Barnhill and Kinuachdrach. The absence of the basement boulder-beds of the Scarba type along this line of junction would thus be accounted for. Pebbly rocks like those immediately above the boulder-bed of Scarba are common near the junction line of the quartzite and pelitic rocks to the south and west of Barnhill. It is on the north-west coast of Jura, however, that some of the upper zones of the Scarba succession can with a reasonable amount of certainty be identified. The calcareous shales and flags with matted worm-casts ("fucoids") of Zone 5 have been recognised on several folds along the north-west coast, between Bagh Gleann nam Muc and Glen Debadel Bay, the best section being exposed at the head of Bagh Uamh nan Giall.† The "pipe-rocks," first described by Sir Archibald Geikie,‡ are evidently the south-western continuation of Zone No. 4 of the Scarba sequence. An interesting feature of the quartzite of this north-west coast is the occurrence at Glengarrisdale of a conglomeratic quartzite, probably on the horizon of Zone 3 of Scarba. This band has a quartzite matrix which, in addition to well-rounded fragments of other rocks, contains large pebbles of syenite (Nordmarkite) like those found in this zone in the Garvellachs. A similar conglomerate occurs near the top of the basal quartzite on the east and north shores of Islay, in a relatively similar position to "fucoid"-bearing shales.§ The whole of the intervening ground between these west coast sections and the Barnhill pebbly grits is occupied by alternations of the intermediate zones of coarser and finer grained quartzites repeated by overfolding.

The Garvellachs, or Isles of the Sea.—This outlying group consists of three main islands and some smaller holms and skerries. Although rocky and remote, they have long been of great interest as the site of one of the seminaries of the Early

* Summary of Progress for 1900, pp. 49-50.
† Summary of Progress for 1900, p. 49.
‡ Summary of Progress for 1898, p. 68.
§ Memoir on "The Geology of Islay," and Summary of Progress for 1900 p. 49.

Columban Church—Eileach an Naoimh, the name still attached to the least barren island, signifies the Seminary of the Saints. The last resting-place of St. Columba's mother is marked by a small cairn a little to the west of the ruins of a primitive chapel, and the beehive houses said to have been occupied by Columba's missionaries are still to be seen in a marvellous state of preservation.

Their geological fame is also of considerable age, as the wonderful boulder-beds did not escape the notice of Macculloch, who, as already mentioned, early in the last century correlated them with those of Islay and Schichallion, and recognised their significance in the study of the schistose rocks of the Highlands.* For convenience of description these islands, which extend in a north-east and south-west direction for about 6 miles, may be taken as a unit, since the same rocks and structures with only slight variations are common to all.

As already stated, two main rock groups enter into their constitution, viz.:—

b. An upper group consisting of a series of conglomerate and boulder-beds interbedded with quartzites and sandy limestones.
a. A lower group, chiefly white limestone associated with light-grey calcareous slaty beds.†

The main limestone outcrops along the steep north-western shores of the main group of islands, where it forms the cores of anticlinal folds overthrown towards the north-west. (Plate IV.) In places denudation has not removed the covering of conglomerate, so that the limestone outcrop is intermittent. It also comes to the surface on two minor isoclinal folds along the eastern shore of Garbh Eileach.

The limestone is white, cream, or pinkish in colour, and in texture a finely crystalline marble. The slates are light-coloured, with alternations of rusty calcareous bands and thin intercalations of white limestone. They are but imperfectly cleaved; indeed, the most striking feature of the rocks of these islands is the very slight amount of metamorphism that they have undergone, the structures due to deposition being everywhere much more apparent than those due to deformation or to chemical or molecular change. The limestone, however, appears to have been slightly affected by contact metamorphism.‡

The relation of the shale and the limestone is evidently that of more or less conformable deposition, although a section on the north side of Garbh Eileach shows evidence of slight overlap, the argillaceous layers ending off against the limestone at an acute angle. The section leaves no doubt that this is due to original deposition and not to subsequent movement.

* Macculloch, "The Western Islands of Scotland," 1819, vol. ii., p. 159.
† The limestone is the thickest and most persistent member of this group, the shales being only exposed in one or two sections.
‡ Summary of Progress for 1902, p. 71.

Except that the limestone and slate are earlier than the boulder-bed, to which they have contributed innumerable fragments, nothing definite can be stated with regard to their position in the metamorphic series. In character they greatly resemble the white limestone and phyllite of Craignish, especially where those rocks have been quarried near Melfort House (Kilmelfort).

The limestone involved in this fold must have attained a thickness of about 40-50 feet, which exceeds that of any band observed in the Craignish phyllites. A thick white limestone of the same character, however, occurs in Appin and near Ballachulish, with a set of phyllites which have been correlated with the Craignish and Ardrishaig phyllite groups. The Isles of the Sea lie more or less along the strike of the Appin outcrop.

White and creamy dolomitic limestone occurs in the "fucoid-beds" in the north of Islay, but can there be demonstrated to overlie the whole of the quartzite group, of which the Portaskaig Conglomerate is the basal member, while the latter is correlated with the boulder-bed which overlies the white limestone at present under consideration. The balance of evidence is, therefore, in favour of regarding this limestone as the reappearance of the Appin Limestone rather than as the representative of the Islay dolomites of the "fucoid-bed" horizon.

Group b.—There is no doubt as to the horizon of the rocks entering into this group, since we can recognise in them the three lowest zones of the quartzite group of Scarba.

The basement beds of the conglomerate immediately overlying the limestone are made up of a tumultuous aggregate of fragments of limestone. Many of them are well rounded and of great size, and they are composed of limestone similar to that which occupies the core of the fold. The section (Plate IV.) shows that there is a certain amount of discordance between the boulder-beds and the limestone and shale of the cores. These two lines of evidence, therefore, both support the view that the junction between the two groups of rocks is an unconformable one, but, as in the case of the relation of the Scarba boulder-bed to the Easdale slate group, do not indicate any great lapse of time between the deposition of the sediments of the two groups.

Further out from the limestone cores, and presumably higher up in the sequence, the blocks are smaller, and the matrix becomes sandy and sometimes black from the presence of much black shale debris. Well-rounded boulders, some of them over two feet across, of rocks foreign to the islands, such as granitic rocks, chief of which is a syenite of Nordmarkite type, felsite, gneiss, schist, jasper, and other rocks are scattered through the beds or arranged in nests or groups along certain layers. (Plate V.) In places these beds become so free from included fragments as to assume the appearance of rusty-weathering sandy limestones, which sometimes attain a considerable thickness. These again are overlain by massive dolomitic beds charged with boulders of the white limestone, as well as rocks

Cliff section, 200 feet in height, on N.W. side of Eileach an Naoimh (Garvellachs). Fold in limestone and overlying "boulder bed." View looking N.E. (p. 31).

foreign to the region. Up to this horizon the rocks probably all belong to Zone No. 1 of the Scarba succession.

Zone No. 2 is represented by a narrow belt of sandy shales with bands of sandy dolomite and flaggy fine-grained quartzite, which traverses the larger islands. Occasional boulders of limestone and foreign rocks occur embedded in the different members of this zone. The quartzites are remarkably pure, and are succeeded by coarse, calcareous, sandy conglomerates with limestone and granitic boulders in a dark-brown weathering matrix. These rusty, calcareous beds merge into and alternate with bands of pebbly quartzite, and finally disappear. Occasional nests of well-worn rounded boulders of limestone, granite, and jasper occur even where the matrix is of pure quartzite. The rocks of this group form a belt along the south-east coast of the larger islands and the outlying skerries, and doubtless represent part of Zone No. 3 of Scarba. The rocks of the first two zones occur on both sides of the anticline. Those of No. 3 zone are found on the south side of it only. It will be remembered that pebble beds begin to appear on this horizon in Scarba, and are strongly represented in the intermediate Eilean Dubh Mor, and that a quartzite containing well-rounded granite pebbles occurs at Glengarrisdale, on the north-west coast of Jura.

The outlying rock of Dubh Fheith, the most northerly of the group, is formed of a coarse calcareous grit with plentiful syenite (Nordmarkite) and limestone fragments, and probably represents a band in Zone No. 1. The study of the rocks on this group of islands tends to confirm Macculloch's sagacious and far-seeing correlation of this boulder-bed with that of Islay and Schichallion.

Mainland.

(B) The following zones or sub-divisions have been recognised in the quartzite group as developed on the mainland, and with slight modifications can be traced throughout the area:—

c. Ardnoe Beds.—A series of fine-grained quartzites with intercalations of grey and dark phyllites and sandy and pebbly limestones. Typically developed in the ground south of Loch Crinan, where they have a thickness of upwards of 200 feet.

b. Pebbly quartzites or coarse grits, with pebbles of blue quartz, microcline, and oligoclase. They contain, near the base, occasional fragments of black slate and limestone, and pass down locally into Zone A. Thickness, 10 to 60 feet or thereabouts.

a. Dark pebbly limestone with similar pebbles of blue quartz and felspar, and sometimes almost entirely made up of fragments of black limestone and slate like those of the Easdale group. This zone is best developed in the Kilmartin area, and varies from a few inches to many feet in thickness, but is not always present. At one point near the head of Loch Craignish this bed (p. 37) becomes a veritable boulder-bed and contains, in addition to limestone, black slate, green phyllite, and quartzite, boulders of felsite, foreign to the region.

The groups described above can be correlated with the zones established in Scarba with considerable confidence. Groups (*a*) and (*b*) evidently represent Zone 1 of the Scarba succession, while the Ardnoe beds (*c.*) are clearly those of Zone 2 of Scarba. The occurrence of fossil worm-casts in the Ardnoe shaly bands further strengthens the evidence for this correlation.

This succession is established on the fact that the Ardnoe type of beds have not been observed, within the limits of the present area, in direct contact with any sediments of the Easdale group. Coarse pebbly beds always intervene, and these must be regarded as belonging to a basement group.

It is, however, extremely doubtful whether every outcrop of pebbly quartzite throughout the area should be considered to belong to the lowest group. It is more probable that periods of coarse sedimentation recurred more than once after the oncoming of the Ardnoe conditions.

In the following sections the quartzite group is described in the several districts in which it is developed on the mainland.

B. N. P.

Area West of Kilmartin Burn.—The dissection of the country east of the Barbreck River by deep valleys running across the strike of the schists permits the examination of the truncated ends of folds in vertical section. Important direct evidence of the nature of the folding and of the succession of the beds is thus obtained. The general structure may be illustrated by a section taken in a north-west and south-east direction through Dun an Dubh Challa, a hill which rises about a mile from the head of Loch Craignish in a N.N.E. direction. (Fig. 4.)

Commencing in the W.N.W. near Barbreck House, the lowest slopes of Corlach consist of pebbly grit and quartzite with several infolds of epidiorite, the dip of the beds being 50°-55° towards the E.S.E. The coarse-grained epidiorite sill follows above, and is succeeded by an alternating series of quartzites and quartzose phyllites with calcareous quartzites, which have been named the Ardnoe beds from Ardnoe Point, near Crinan, where they are well developed. Into this series a thin sill of porphyritic epidiorite is intruded, and in the cross-section at the southern end of the hill is proved to lie in a reclining syncline. The massive sill of epidiorite is then repeated above the Ardnoe beds and caps the hill. It is succeeded to the east by quartzites with slaty bands and pebbly grits, which dip E.S.E. at 60°-65°. Black leaden schists with a few very thin calcareous bands then crop out, and are quickly succeeded by pebbly grits, which are, however, separated along part of the junction by a band of brown-weathering quartzose limestone. The pebbly grits are again succeeded by a broad zone of black schist, which includes several lenticular outcrops of dark blue finely-crystalline limestone. The centres of one or two of these lenticles are occupied by the pebbly limestone, whilst one contains a core of calcareous pebbly grit. One outcrop of pebbly limestone is immediately surrounded by black schist, but contains numerous blocks of

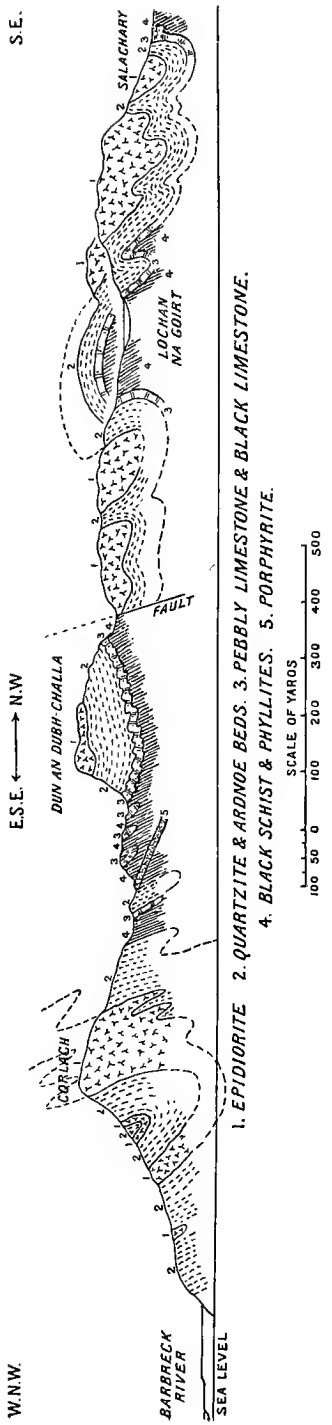


Fig. 4. SECTION FROM BARBRECK RIVER TO SALACHARY.

black limestone, apparently derived fragments, since the conglomerate has not the usual aspect of a crush-conglomerate.

Immediately to the east of the black schist and limestone outcrop, the hill called Dun an Dubh Challa rises up. It consists of a thick mass of pebbly grit and quartzite, which is bent into a shallow syncline, and bears two outliers of the massive epidiorite sill. The grit is made up of pebbles of milky-white or faintly-bluish quartz and pink and white felspar, embedded in a granulitic matrix consisting of small grains of quartz and felspar with some mica. The majority of the felspar pebbles are of microcline, whilst the rest appear to be either perthitic orthoclase, or oligoclase. Rock fragments are not common, but one or two pieces of black schist and limestone and a small pebble of pegmatite were noticed.

The limestone and black schist have been traced completely round both ends of the hill beneath the pebbly grit. The junction is often obscured by screes, but when visible it is found that the pebbly grit, which is often calcareous at the base, rests sometimes on the rusty-weathering limestone, sometimes pebbly limestone intervenes between the two, whilst along a portion of the eastern margin the pebbly grit is in contact with the black schist for a short distance. At the south-eastern corner of the hill greenish phyllites, similar to those of Craignish, appear beneath the black schist.

Immediately to the east, and separated from the phyllites and black schists by a fault, is a broad outcrop of the massive coarse-

grained epidiorite. Narrow lenticular outcrops of pebbly grit occur within the epidiorite. The sill is bounded on the east by a belt of pebbly grit, which dips steeply to the E.S.E. as if it were overlying the epidiorite, but an examination of the gorge beside the road at the south end of the outcrop shows that the pebbly grit really underlies the epidiorite, and that the belt of grit mentioned above is brought up by an anticline, which is reclining towards the west. The lenticular outcrops of grit mentioned above must therefore be the tops of sharp anticlines exposed by denudation.

At the head of Lochan na Goirt, the black slates again crop out. They are separated from the pebbly grit by a narrow band of black limestone, whilst the presence of pebbly limestone is indicated by blocks of that rock along the edge of the pebbly grit. A little north of the lochan a slight, but sharp, rise of the ground enables the outcrop of the pebbly grit to be carried around and above the outcrop of the limestone and black schist. On the eastern side of the fold the quartzite dips to the E.S.E. beneath the massive coarse-grained epidiorite. This last occurrence of epidiorite may, a few hundred yards further north, be traced completely round the outcrop of grit, proving that we are here dealing with only one sill of epidiorite. That the fold just described is really an anticline and not a syncline affected by a pitch to the south is evident from a consideration of the fact that the quartzite is seen to underlie the epidiorite on both sides of the fold, and from a consideration of the succession in the shallow syncline of Dun an Dubh Challa.

The sections detailed above are considered to prove the succession of beds given on p. 23.* Many other sections in the area support the interpretation, and, although some are obscure, none are altogether inconsistent with it. One or two of these sections will now be referred to.

The small hill immediately west of Lochan Fearphorm consists of the massive sill of coarse-grained epidiorite bent into a gentle anticlinal fold. At the northern end of the hill the pebbly grit is seen underlying the epidiorite, whilst in the core of the anticline a mass of black limestone is exposed. Pebbly limestone is seen in one place to intervene between the black schist and pebbly quartzite.

The next hill to the west is a shallow syncline of pebbly grit capped by massive epidiorite. Below the grit is a bed of contorted black limestone with some pebbly limestone, whilst the lowest beds exposed on either side of the hill are dark phyllitic schists.

On the eastern flank of a north and south hollow, and about 400 yards north-east of Lochan Fearphorm, about 10 feet of pebbly grit with a thin, finely-laminated quartzose band at the

*Always supposing the whole district is not dissected along the inverted limb of a very large fold. This possibility is precluded by the occurrence of fragments of black schist, etc., in the pebbly grit, a fact which forces the conclusion that the pebbly grit is one of the youngest members of the series.

base rests on 4 feet of pebbly limestone, which contains blocks of black limestone. The pebbly limestone in turn rests on dark limestone without pebbles, the even bedding of which is marked by numerous thin quartzose laminæ. The pebbly limestone with a row of pebbles along its base cuts across the bedding of the black limestone. There is no sign of movement along the junction of the two limestones, which is clearly a slightly unconformable one.

At the south-eastern corner of Lochan Druim an Rathaid there is a gentle anticlinal fold of quartzite within which is a bed of black limestone with calcareous slaty bands, whilst the core of the fold is occupied by black schist. Between the limestone and pebbly grit a band of pebbly limestone is occasionally seen. Massive epidiorite overlies the eastern limb of the quartzite, and is succeeded to the east in inverted order by pebbly grit and pebbly limestone.

A boulder-bed is found in this pebbly limestone 300 yards E.N.E. of Ormaig. The boulders are usually 4 to 9 inches in length, but several much larger ones were noted. They consist of yellowish fine-grained quartzite, phyllite, and a peculiar felsite. The fine quartzite and felsite boulders are rounded and apparently waterworn, but the phyllite blocks are often angular. A careful search failed to reveal any pebbles of epidiorite or pebbly grit. The absence of these rocks, which here lie next to the pebbly limestone, together with the presence of an igneous rock foreign to the locality, preclude the possibility of the bed being a crush-conglomerate. The boulders of quartzite and phyllite can be matched with beds of the Craignish phyllite series, and were probably derived from them by denudation at the time when the pebbly limestone and pebbly grit were being formed.

H. B. M.

A section drawn from west to east across any part of the Kilmartin area south of that last described, and as far south as the Crinan Canal, would show, with only slight local modifications, an arrangement of the rocks of the quartzite group in their relations to the other rocks of the region similar to that figured and described in the preceding paragraphs.

A band of the Ardnoe beds (*c*), occupying the centre of a synclinal overfold, skirts the shore of Loch Craignish as far south as Craig Bhanan. It is succeeded by a belt in which the pebbly quartzite and associated epidiorite sills are repeated on successive folds, none of which have been sufficiently denuded to expose the underlying rocks. Further to the east the pebbly limestone (*a*), resting on dark limestones and slates of the Easdale group, and showing evidence of local erosion here and there along the junction line, appears on the crests of anticlinal folds. Still further eastwards, where denudation has cut deeper into the shallow folds, the pebbly limestone and underlying dark slates and limestone occupy more and more of the surface in proportion to the quartzite, while the cores of the anticlinal folds are occupied by the Craignish phyllites.

In the ground that extends N.N.E. from Slockavullin to the margin of the map, the pebbly limestone forms nine-tenths of the limestone area shown on the map, the overlying quartzite being confined to isolated outliers lying in the deeper synclines. On the west side of the valley, north of Kilmartin, the greater depth of the folds reveals more of the latter rock. A similar arrangement of the strata obtains on the east of the Kilmartin valley. A compound syncline, including the quartzite, is followed by a compound anticline which reveals grey phyllites of Craignish type; and this again by folds in which appear, first the black slate and limestone, followed in turn by the pebbly limestone and overlying quartzite.

The pebbly limestone, in addition to containing pebbles of blue quartz and felspar identical with those found in the overlying quartzite, is in places a derivative rock made up of fragments of black limestone like that associated with the Easdale slate and of the black calcite found at Degnish, Shuna, and near Old Poltalloch, within the present area.

Good examples of this derivative rock occur on most of the outcrops, and especially at the highest point of the road that comes from the Kilmartin Valley to Old Poltalloch.

The limestone sometimes contains so many grains of quartz and felspar as to become a calcareous grit, and passages from the black limestone through such a grit (out of which the calcareous matter has been dissolved) into the massive pebbly quartzite are not uncommon, as, for instance, to the west of Slockavullin. The pebbly quartzite in all its phases can be conveniently studied along the road between Kilmartin and the head of Loch Craignish. B. N. P., J. S. G. W.

Area East of Kilmartin Burn.—In an earlier section describing the Easdale slate and limestone south of the Crinan Canal it was pointed out that those members including the quartzite make up the Loch Awe group. It was also shown that the pebbly limestone graded into the normal limestone, and that so far as this area is concerned they could not be differentiated. About half a mile south-east of Poltalloch a large exposure of limestone occurs, varying in texture from the coarsely conglomeratic type to the finest-grained blue variety, and passing even into calcareous slate. With it quartzite bands occasionally occur. Limestone exposures with similar lithological variation emerge from the alluvial terraces to the north of Poltalloch.

In the area lying to the east of Kilmartin Glen and the Crinan Moss epidiorite is widely developed, and the members of the Loch Awe group occupy narrow strips between the epidiorite sills. The limestone is here strongly represented, and forms large irregular bands running approximately N.N.E. at Killinochonoch, Balameanoch, Baluachraig, and to the east of Kilmartin and Largie. These bands show the same lithological variation as those just described from near Poltalloch. Moreover, their interfolding with tougher rocks at their junction has resulted in the production of crush-conglomerate. Such

structures may be seen near Balameanoch, to the south of Kilmartin. In this area the black slates are subordinate, but occur in association with the limestone and grits.

The grits which occur in association with the limestones and black slates are poorly represented in this area. South of the Rudale Valley, however, they are more conspicuous, and occur together with phyllites between the epidiorite sills. J. B. H.

District South of Loch Crinan and the River Add.—In the area between the River Add and the Crinan Canal the members of the quartzite group appear between the long ridges of epidiorite on either side of the central belt of black slates and limestones of the Easdale Group. On the eastern side the slates are flanked by pebbly limestone associated with quartz schist, while further to the east the pebbly quartzite, separated from the limestone by a thin epidiorite sill, makes its appearance, and is well exposed in quarries by the side of the Kilmartin road.

Near the Cairnbaan Hotel, on the Canal, a bluish somewhat sandy limestone is visible, associated with the quartzite. This sandy limestone is the normal Loch Awe type found in the area between the Crinan Canal and Inveraray, on the eastern margin of the Loch Awe group. In its extension north-east this band becomes in places conglomeratic, and contains large pebbles of quartz, felspar, slate, and quartzite. The dip is steep to the north-west. B. N. P., J. B. H.

South of the Crinan Canal.—The black pebbly limestone (Zone *a*) is well exposed along the crest of the Dunardry compound fold, by which, as described in Chapter III., the Easdale slate group is brought to the surface. The indications of slight discordance in the relations of the two sets of rocks have also been referred to. At one or two points a passage of the pebbly limestone into the overlying quartzite can also be detected, where small outliers of the latter are seen resting directly upon the limestone without the intervention of an epidiorite sill. Such instances occur near a ruined house a little south-west of the Dunardry lock, on the west side of the locks that lead to the summit level of the Canal.

The same passage can be observed on the west side of the old road, to the north of Loch Fada, where the pebbly quartzite occupies a long synclinal trough that extends to the margin of the sheet, separated from the wide spread of quartzite to the east by an upfold of the limestone.

The hill of Cruach na Speireig is formed by repeated folds of the pebbly quartzite, and the Ardnoe beds with their phyllite partings and sandy limestones are well displayed along the Carndubh Burn.

Passing westwards from the Dunardry folds of Easdale rocks, and crossing the outcrops of the pebbly limestone and the accompanying broad sill of epidiorite, the observer finds the whole country as far as the head of Caol Scotnish, with the exception of the minute inliers of Easdale rocks and the igneous intrusions, to be occupied by the members of the quartzite series.

The centre of this belt coincides with the great axis of foliation of the region, and the axial planes, at this point vertical, are more and more inverted as we pass outwards on either side of the central axis, so that the strata appear to dip inwards at lower and lower angles. The sections seen on the high banks above the road between Dunardry lock and Crinan show that the amplitude of these highly-compressed folds must be considerable, while the disposition of the Ardnoe beds, which occupy each successive trough, attest to their regularity. This structure is admirably illustrated on the map by the succession of elongated rings of epidiorite—the remains of once continuous sills that have been isolated by denudation—shown in the ground to the south of the road. The disposition of the few outcrops of the limestones of this zone (*c*) which the small scale of the map allows of representation also serves to emphasise this point of structure. Further to the west the folding is of a more complex nature.

The flaggy quartzose beds with phyllitic partings of the Ardnoe series are well displayed along the winding road between Bellanoch and Caol Scotnish. One of the bands of pebbly limestone is sufficiently thick to have been wrought and burnt for lime at a point near the road a little to the east of the head of Loch Coille Bharr. B. N. P.

Over much of the district immediately south of Loch Crinan the strata are inclined towards the E.S.E. at varying angles, and a considerable amount of isoclinal folding may reasonably be suspected, although we have no definite knowledge of the extent to which this structure is here developed. There are, however, important exceptions where the folding, so far as it meets the eye, is open and simple. In such cases the structural details have been most clearly exposed by denudation. Creag Mhor is thus seen to represent the eastern limb of a syncline, into which the quartzites and accompanying early intrusions have been thrown. The Creag itself is composed of epidiorite, dipping at an angle of 70° or 80° to the W.N.W., but rising again in the western limb before reaching the sea with a gentler inclination of 45° towards the E.S.E. This obvious syncline has a pitch towards the S.S.W., causing the outcrops of successive beds of quartzite to swing round and enclose the epidiorite of Creag Mhor. This basin is succeeded on the east by an anticline which follows the west side of Glen Sabhail, while another anticlinal axis extends from Cnoc Biorach and An Garadh in the south to the shore of Loch Crinan, opposite Eilean da Mheinn.

This district is also the type-area of the Ardnoe Beds, and their sequence as developed in the cliff-sections south of Ardnoe Point will now be briefly described.

The pebbly quartzites are succeeded below* by strata in which grey slates are predominant, but which also contain many

* The structural peculiarities of this district are discussed in the sequel.

"Boulder Bed" with granite and limestone boulders in the Garvellachs (p. 32).

quartzite and sandy limestone bands. These are followed by a middle division of purer fine-grained quartzite, which in turn is succeeded by the most characteristic portion of the zone, composed of flaggy quartzites separated by thin grey sandy limestones and slates. What appear to be worm-casts ("fucoids") were found in sandy shales belonging to the group at this locality. Their occurrence is important as supporting the suggested correlation between the Ardnoe Beds and the flaggy quartzites of Scarba.

At Ardnoe Point fully 200 feet of beds belonging to this zone are seen, but this evidently does not represent their full thickness.

The relations of these Ardnoe Beds to the pebbly quartzite and Easdale slates are best seen at Ardnackaig, three miles to the S.S.W. of Ardnoe Point.

The Ardnackaig outcrop of the Easdale slate group is very restricted and occurs within the limits of the 100-foot beach. The black slates clearly occupy a steep-sided syncline pitching towards the S.S.E. Next to the slates, and exposed in a bank at the northern end of the outcrop, comes a bed of dark limestone containing pebbles of quartz and felspar. This is followed by a band of pebbly quartzite, which passes round the northern end and along both sides of the limestone outcrop, and probably completes its circuit to the south, beneath the beach material. This pebbly quartzite, about twenty feet thick, is succeeded in descending sequence as the beds lie by a thin sill of epidiorite, which can be traced along the western margin of the pebbly quartzite around the north end of the fold. Beyond this epidiorite is a narrow outcrop of flaggy quartzite, followed by another thin epidiorite sill. As the latter is traced along the western shore of Sailean na h-Earba it also follows for a time the flexure of the inner zones, till, folding suddenly back upon itself on an anticline, it runs seaward into Sailean Mor. The flaggy quartzites outside and below this epidiorite contain occasional beds of sandy limestone; but these are soon followed by still another epidiorite sill which runs up the Rudha Caol, then makes the double bend noticed in the preceding case, and passes out to sea again in the Rudha nam Barr. From beneath this emerge flaggy quartzites in which the sandy limestone intercalations have attained a very important place, and it is evident that we are dealing with the Ardnoe Beds (Zone *e*), The well-banded nature of the strata accentuates the rapid changes of strike at Rudha nam Barr, while, on the other hand, the cleavage remains constant, dipping always steeply to E.S.E.

From the description given above, it will be seen that the sequence from the Easdale Slates to the Ardnoe Beds, already given in the general classification of the Quartzite group, is here inverted, the Ardnoe Beds in the Ardnackaig section underlying the pebbly quartzite, which in turn underlies the Easdale Slates. This same relation probably holds at Ardnoe Point itself, where typical Ardnoe Beds are overlain in very flat folds

by pebbly quartzite, and it is possible to walk south on the latter to the outcrop of Easdale Slates in Glen Sabhail without ever recrossing an outcrop of the Ardnoe Beds.

This inversion forms the structural peculiarity of this district, and distinguishes it from the Kilmartin area to the north, where the black slates are exposed in the anticlines and the quartzite in the synclines.* Hence it would appear likely that there is large-scale overfolding in this district of much greater magnitude than that which at first attracts attention. According to this view a whole district, such as the Kilmartin area, may be carved out of a single limb of a great recumbent fold, and in consequence show throughout, apart from minor local inversions, a definite succession, *e.g.*, from the Easdale Group into the Quartzite Group. On the other hand, a neighbouring district, such as that south of Loch Crinan, may be carved wholly or in part from the complementary limb of the same recumbent fold, and accordingly exhibit an exactly reverse sequence, *e.g.*, from the Easdale Group down into the Quartzite Group. It is noteworthy that Mr. Clough has already brought forward strong evidence for the existence of a large-scale recumbent fold of this type in the Cowal District of Argyllshire to the south.

E. B. B.

* The explanation of the structure south of Loch Crinan given in the foregoing paragraphs is advanced tentatively and may be modified by further research.

CHAPTER V.

METAMORPHIC ROCKS—*Continued.*

OLDER IGNEOUS ROCKS—EPIDIORITE.

Under this category two groups of more or less basic igneous rocks associated with the metamorphic strata fall to be described.

I. A group of sheets which follow the bedding planes of the sediments with which they are associated, and share in the movements which have folded the latter and rendered them schistose.

II. A group of well-defined basic dykes, which cut the folded schistose rocks. These are of earlier date than, and can be clearly distinguished from, both the "Newer" granites, porphyrites, and other dykes of Lower Old Red Sandstone Age, and the Tertiary basalt dykes.

I. *Epidiorite—mostly in Sheets.*

As already pointed out, the earlier epidiorites find their greatest development on the mainland east of Loch Craignish, and die out towards the west.

Among these rocks, which vary much in texture, two main types are easily distinguishable in the field, viz.:—

(*a*) A fine grained rock, often slaggy or amygdaloidal at its margins, and sometimes presenting an arrangement of phacoids with vesicular outer layers, suggestive of the "pillow" structure found in certain lava-flows. This type of rock is usually associated with the black pebbly limestone and the rocks of the Easdale Slate Group. The resemblance of these rocks under the microscope to certain basic lavas has been noted by Dr. Teall* and several other observers.

The discovery of undoubted "pillowy" basic lavas associated with pebbly limestones and boulder-beds in the peninsula of Keils,† a little to the south of the present area, renders it highly probable that some of the rocks in the region now under consideration represent contemporaneous lava-flows. No alteration of the sedimentary rocks with which they are associated has been observed which could be ascribed to these lavas.

This type of rock is often much affected by dynamical metamorphism. The phacoids are elongated in the direction of the strain-slip cleavage, and the rock often passes into a cleaved

* "The Silurian Rocks of Scotland."—*Memoirs of Geological Survey of Scotland*, p. 85.

† Summary of Progress of the Geological Survey for 1903, p. 69.

and platy hornblende-chlorite-epidote-schist, which might easily be taken for a rock of sedimentary origin.

(*b*) More massive rocks of coarser texture, often showing traces of ophitic structure with few or no vesicles. Where these rocks are associated with impure limestones and phyllites they often produce the hornfels type of contact-metamorphism in these sediments. Their texture and behaviour in the field show that they are in almost every case intrusive.

On the mainland, epidiorites are found associated with the schists at different horizons from the Craignish phyllites up to the Ardnoe beds of the quartzite group. B. N. P.

Craignish.—The sills of epidiorite intruded into the phyllites are on the whole thinner than those associated with the schists on the east side of Loch Craignish, but, as in the latter district, a coarse-grained, massive kind may be distinguished from a finer-grained, cleaved hornblende-schist. The planes of schistosity are cleavage-planes, along which shearing has taken place, probably during the production of strain-slip cleavage in the phyllites.

The big sill north of Ardfern is an example of the massive type of epidiorite. The phyllites beneath it are indurated for about a foot from the junction, and it is evident that the induration has been superinduced prior to the development of cleavage in the district. In fact, the contact-altered rocks have not developed sericitic mica along the incipient cleavage-planes sufficiently to deserve the name of phyllite. Another good section, which shows a sill of epidiorite transgressing the bedding of the phyllites and indurating them, occurs on the promontory on the north side of Bagh an Tigh Stoir.

On Eilean Mhic Chrion the contact-altered slates are seen on both sides of the sill, but since on Eilean Dubh they can be traced running right under the sill, it is evident that the sill lies in a sharp synclinal fold of phyllites, which is reclining towards the west.

On the hill called Mullach Dubh there are two sills repeated in lenticular outcrops arranged *en échelon*, but as the bands of phyllite between the outcrops are usually too narrow to be represented on the one-inch scale, several outcrops have been run together on the map. H. B. M.

Kilmelfort and the Islands.—The Craignish sills are continued into the islands south of Craignish Point and northwards into the ground between Craignish and Loch Melfort, where they are hardened and altered as they approach the granite intrusions. At the head of Loch Melfort they show similar contact-metamorphism, but they resume their ordinary character a little to the west of Melfort, where they pass under the volcanic pile of Lower Old Red Sandstone age. A single sill only is found on Scarba, and a coarse-grained example of type (*b*) appears to occupy a compound fold that extends through Seil and Torsay into Luing. B. N. P.

Area North and West of the Kilmartin Burn.—In the hilly country east of the Barbreck River a thick sill of coarse-grained, massive epidiorite is intruded into the pebbly quartzite and is interfolded with it. At least two other thinner sills are intruded

into the Ardnoe beds on the hill-slopes east of Turnallt. One of these is fine-grained and contains phenocrysts of plagioclase about a quarter of an inch long. The preservation of these phenocrysts is probably due to the fact that the sill lies in synclinal folds of the pebbly quartzite and massive epidiorite, and hence has suffered relatively little shearing. The induration of some argillaceous quartzites of the Ardnoe beds near the contact with epidiorite is seen on the eastern flank of Corlach.

The big epidiorite sill of Corlach and Dun an Dubh Challa (*see* Fig. 4) must slowly transgress the bedding by descending to lower horizons in an easterly direction, since about half a mile north of Salachary it comes in contact with and causes considerable alteration in the black limestone.

East of Salachary, on the margin of the map, well-cleaved hornblende-chlorite-schists are interfolded with the limestone and black schist. Although good junctions are not common, contact alteration of the sediments has not been observed. The presence of pillowy bodies, a foot and a half to two feet long, elongated parallel to the planes of schistosity, and consisting of an outer coating of vesicular epidiorite about a more schistose centre, suggests that these fine-grained schistose epidiorites may really be lava-flows contemporaneous with those described from districts to the south. (Fig. 5.) There are probably at least three of these "flows," but nothing in the nature of an ash or agglomerate has been noticed in this district. H. B. M.

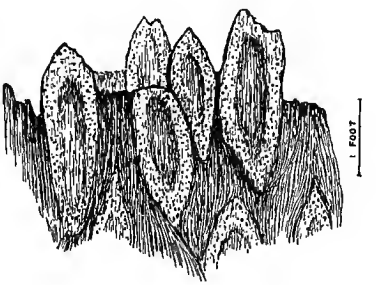


Fig. 5.—Pillow-like bodies in hornblende-chlorite-schist near Salachary.

In the Kilmartin area, south of the ground described in the preceding paragraph, the two types of epidiorite are well represented and cover a wide extent of ground.

A good example of the (*a*) type of rock is exposed in a road-cutting, where the road between Craignish and Kilmartin has been widened on the steep hill about two miles north of the latter place. At this point one or two rows of compressed phacoids of epidiorite, highly inclined to the south-east and enveloped in pebbly limestone, are seen overlying a sheet of epidiorite. It is highly probable that these compressed phacoids

may represent the pillowy surface of an original lava flow. These fine-grained slaggy rocks are also well developed immediately west of Slockavullin, again in connection with the pebbly limestone.

The more massive and coarse type (*b*) forms the broad belts which cap the higher ground, and frequently rise in steep escarpments facing west. A good example of this type of epidiorite is seen in the wide sill which extends southwards down the west coast from Ormaig to Duntroon Castle.

Another very coarse-grained sill is intruded into the Craignish phyllites in the neighbourhood of Poltalloch, and can be traced north to a point opposite Slockavullin. Where this epidiorite appears on the shore of Loch Crinan, near Duntroon Castle, it has converted the impure calcareous bands of the phyllites into calc-silicate hornfels. J. S. G. W.

Area East of Kilmartin and South to the Crinan Canal.—The epidiorites are the dominant type in this area, and, except as regards the small district south of Cairnbaan, occupy a larger part of the ground than all the other rocks taken together. To the east of Kilmartin the continuation from Loch Awe of a large epidiorite sill, which in the adjoining ground to the east (Sheet 37) sometimes reaches a breadth of five miles, enters the map. Amongst this mass strips of sediment are embedded; while fringing it, the sills of epidiorite, though large and numerous, form discontinuous intrusions enclosed by sediments. Although portions of this sill are typical epidiorite, it includes rocks to which this term cannot apply. It shares in the varying amount of metamorphism of the sediments with which it is associated. The mass, which is sometimes vesicular, varies in composition from basic to intermediate. The dominant minerals are hornblende and plagioclase felspar, with chlorite, epidote, calcite, quartz, and iron ores as the most important accessories. There is every gradation in structure from a coarse gabbro-like type to the finest schist. It is sometimes very coarse, often foliated, consisting of hornblende and felspar, the hornblende occurring in platy crystals up to half an inch in length, and the felspar in elongated prisms, while epidote is abundant. Zones of finer texture composed of hornblende and felspar also occur; in these the rock is massive and compact, and approaches a fine schistose diorite in character.

The most prevalent type of rock is a felspar-hornblende schist, with bands of fine-grained chlorite schist. In both these varieties porphyritic and idiomorphic phenocrysts of felspar are present in varying quantity—sometimes so abundantly as to form the greater part of the rock, and sometimes altogether absent. These phenocrysts are often fractured and have their outlines rounded, but have on the whole suffered very little deformation. The groundmass of the rock also varies both in texture and in composition. These differences of structure and composition are so sharply accentuated as to produce banding. In the chloritic varieties the rock passes into a green schist or slate which, when the porphy-

ritic felspars are absent, cannot readily be distinguished in the field from a sediment. Although portions of the mass show porphyritic hornblende, this type is not common.

While, as a whole, the rock is fairly fresh, considerable masses are in a highly decomposed condition, in which the hornblende has completely broken down, though minute individuals of felspar often remain. When these latter are absent the igneous character of the rock is obliterated. In this condition the rock becomes very calcareous, from the breaking down of the lime-bearing hornblendes and felspars, and possibly also from the decomposition of the big limestone masses with which these rocks are associated. The gradual passage of the normal epidiorite into these nondescript green calcareous schists can be readily observed.

Epidote is a common constituent in the epidiorite, and occurs either as grains in the rock or in a more massive condition in cores, veins, and strings, intermixed with quartz, and forming epidosite. Cores of epidosite from a few inches to a foot or more in length pervade all varieties of the rock, and in the calcareous chlorite schists are often the sole remaining link to connect them with the unaltered epidiorite.

Besides epidote, minute crystals of albite, similar in appearance to the mineral which characterises the albite schists of Cowal, have been occasionally observed.

This large epidiorite mass may be seen in contact with any of the different members of the Loch Awe group, but its base appears to coincide in a general way with the horizon of the limestones. It has produced contact metamorphism in the limestone, the black slates, and the quartzite. The vesicular varieties usually occur at the base. Although there appears to be no doubt of the intrusive origin of this sill, many of its vesicular portions closely simulate the structure of the pillow lavas found in association with radiolarian cherts both in Cornwall and at Ballantrae. Moreover, pillow lavas have recently been discovered in North Knapdale in the map to the south (Sheet 28). It is possible, therefore, that these vesicular varieties may not have consolidated at a great depth from the surface.

The sills which occur beyond the limits of this large mass call for no special comment, as they consist of types which are represented within the mass above described. The folding of the district is often admirably illustrated by these epidiorites, as, for instance, on the low tableland north of the summit level of the Crinan Canal. J. B. H.

Area South of the Crinan Canal.—Both types of epidiorite enter into this part of the ground, the fine-grained slaggy type (*a*) being associated with the rocks of the Easdale group and the pebbly limestone on the Dunardry folds. There can be little or no hesitation in regarding some of these epidiorites as contemporaneous lavas, since undoubted "pillowy" lavas have been recognised by Mr. Bailey a little further to the south along the same line of strike at Kilmichael, near the head of Loch Sween.

A peculiar sill of coarse epidiorite showing traces of ophitic structure has, as already mentioned, been intruded along almost the whole of the junction line between the pebbly limestone and the quartzite. Owing to its great thickness and tough nature, this sill has proved singularly resistant to denudation, and extends widely over the surface on successive folds, especially in an eastward direction.

Further to the east two sills at least of the coarser type occur within the quartzite, the Ardnoe beds having evidently offered an easy passage for their intrusion. The isolated rings of epidiorite seen in this region are, as described in an earlier chapter, the remains of once continuous sills now isolated by denudation, while some of the masses with complicated outlines on either side of Loch Coille Bharr are probably due to the reappearance of the sill on the lower horizon, laid bare upon a series of compound anticlinal folds which pitch towards the north.

B. N. P.

Almost every ridge of the country to the south of Loch Crinan is determined by the outcrop of an epidiorite sill, usually of the basic porphyritic type well known in the west. Cnoc na Faire (south-west coast), however, offers a peculiar type containing quartz, which is probably original, and perhaps orthoclase. Whether it is in connection with any of the more normal epidiorites is uncertain, as its relations are somewhat obscured by peat. The same type of rock is found again to the south in Sheet 28.

Many sections show clearly the transgressive nature of the margins of the epidiorites, and there is no reason to believe that any of these masses in this area are other than intrusive rocks. From ridge to ridge a sill of epidiorite may, however, often maintain its relations to a particular sedimentary sequence, so that it is evident that but gentle folding of the strata can have preceded the injection of these sills. Now they not only follow the folds into which the quartzite has been thrown, but are all more or less deformed and cleaved in a direction parallel with the general cleavage of the rocks with which they are in association.

The actual number of sills present in this part of the district has not been ascertained.

E. B. B.

II. *Epidiorite Dykes of Jura, Scarba, and Lunga.*

Certain basic dykes mapped in the central and more southerly parts of Jura by Mr. Wilkinson* were manifestly injected into the quartzites after the latter had been folded and metamorphosed. The prolongation of the movements during, and even after, their consolidation was also indicated by the foliation of the marginal portion of some of these dykes in a direction more or less parallel to their sides. The phenomena

* Summary of Progress for 1898, p. 51.

were compared by Dr. Teall, to whom specimens were submitted for microscopical examination, to those observed by him in the "Scourie Dykes" in the Lewisian gneiss of the North-West Highlands. The subsequent survey of the part of Jura included within this map, and of the islands of Scarba and Lunga, has shown that dykes of this type are even more numerous here than in the southern part of Jura, and that they attain their maximum development in the extreme north of Jura and Scarba, dying out again in the islands further to the north.* Their absence from the rocks lying to the east of these islands has already been referred to. In the present area the dykes differ somewhat in direction from those first encountered. That of the main set of dykes, which appear to run in sheaves, is nearly north and south, but there are a few exceptions in which the direction is N.N.W. to S.S.E., and a single instance, near An Carn, on the east coast of Jura, of a dyke running north-east and south-west. In Scarba the north and south dykes cut the only one which has a N.N.W. and S.S.E. trend, showing that the period of injection must have lasted over an appreciable time, and was not simultaneous over the whole area.

Most of the epidiorite dykes on Scarba are more or less foliated along their margins, which also bear evidence of rapid cooling prior to the foliation, while some of the thinner intrusions are foliated throughout and have become flaky hornblende-chlorite schists. The dykes show, as already stated, a tendency to group themselves in sheaves, the larger examples being usually accompanied by smaller ones to which they have evidently acted as feeders.†

In addition to participating in the subsequent movements of the area, indicated by the evidence adduced above, these dykes have been shifted and sometimes repeated by a series of thrust-planes dipping gently to the south-east. Along some of these planes sills of lamprophyre have been intruded after the movements had entirely ceased, as shown by the unaffected condition of their chilled edges.

These dykes are also traversed by the lamprophyre and porphyrite dykes of Lower Old Red Sandstone age, a fact first observed in the north-west of Jura and subsequently confirmed in the survey of Scarba and Lunga.‡ One of the best examples of the intrusion of a porphyrite into a foliated basic dyke is afforded by the single example of the latter type found on Lunga. On the west coast of that island, and opposite the skerry of An Tudan, a dyke or sill of porphyrite follows for some distance the foliation planes of the quartzite, but on reaching the foliated epidiorite dyke sends off a long protrusion into the latter. This protrusion rises vertically through the epidiorite, and can be traced in company with it southwards for half a mile to the southern coast, where it passes out to

* Summary of Progress for 1900, p. 50; for 1902, pp. 76-77.

† Summary of Progress for 1900, p. 50.

‡ *Op. cit.*, p. 50.

sea. Near the shore this compound dyke is also cut by a north-west and south-east Tertiary basalt dyke. Similar phenomena occur on Scarba, the best examples being found on the rock-notch or platform which underlies the cliff at the extreme western point of the island. B. N. P.

PETROLOGY OF THE EPIDIORITES.

The petrographical characters of the epidiorites are sufficiently uniform to justify their treatment as a single group, which, however, may be broken up into a number of sub-divisions according to their composition, their original structures, and the degree of metamorphism they have experienced.

In the hand specimens many of them are schistose; this is especially the case when they contain much chlorite and amphibole. Others, however, have almost a massive appearance, and among these ophitic, porphyritic, and vesicular types occur. Their prevalent colours are dark green owing to the abundance of chlorite and amphibole. Biotite is rarely conspicuous, but crystals of plagioclase felspar, often broken and granulitised, are very frequently observable. In the vesicular rocks amygdules of calcite, quartz, and chlorite are usually numerous, and where extensive crushing has taken place they become flattened into lenticles which accentuate the foliation. These amygdules weather out on exposed surfaces of the rocks, leaving rounded or elongated cavities. Quartz veining is never pronounced in this group of rocks, but irregular patches of yellowish epidosite frequently make their appearance. Where the crushing is very intense, thin seams of chlorite schist, mingled with carbonates, are commonly found.

These Argyllshire epidiorites differ markedly from those of most of the Southern Highlands in the low degree of metamorphism they exhibit, and the perfection with which their igneous structures are preserved. In Aberdeenshire, Perthshire, and the eastern parts of Argyllshire the epidiorites are mostly typical crystalline metamorphic rocks showing few remains of their original characters either in their structure or in the nature of their minerals. Mr. J. B. Hill* has pointed out that the region of Loch Awe is one of low metamorphism, and this extends into Crinan and to the shores of the Sound of Jura.

The essential minerals of the epidiorites are green hornblende, chlorite, and felspar, with biotite, epidote and zoisite, sphene (leucoxene), apatite, quartz, and carbonates. Augite is very rare, and olivine has not been seen in any of these rocks. The hornblende is of a green colour, sometimes pale with feeble dichroism, at other times grass-green and strongly dichroic. It is not as a

* Hill, J. B.—"On the Progressive Metamorphism of some Dalradian Sediments in the Region of Loch Awe." *Quart. Journ. Geol. Soc.*, vol. lv., p. 470 (1899).

Hill, J. B. (and others).—"The Geology of Mid-Argyll." *Memoirs of the Geological Survey, Scotland* (1905).

rule well individualised, but occurs in irregular plates with frayed edges, or as fibres which are often felted together with chlorite, biotite, and other minerals. Clear, well-crystallised grains are very rare except where the rocks have been contact-altered by the Devonian granites. In some of the specimens there are fibrous pseudomorphs of carbonates replacing hornblende. The chlorite, like the hornblende, is green, and often the two can hardly be told from one another except with crossed nicols. They have the same colour, very much the same dichroism, and both are imperfectly crystallised. In polarised light the interference colours of the chlorite are pale grey or dark brown or blue, and polysynthetic twinning may sometimes be detected. The felspar, often more or less idiomorphic, though occasionally crushed and broken, is mainly oligoclase-albite and albite. It has the low refractive index and low specific gravity of the most acid plagioclases, and has angles of symmetrical extinction which are often too high for normal oligoclase. More basic varieties of felspar are rare. Most of the crystals show albite twinning; pericline twinning is less common; Carlsbad twinning is seldom observed. Epidote, chlorite, calcite, and iron ores occur in the felspar, and needles of bright green amphibole may penetrate it from adjacent clusters of hornblende crystals. The felspar is rarely zonal except for the presence of an outer border of less turbid material which may be a secondary deposit. In some of the rocks aggregates of epidote and quartz or of sericitic mica appear in the place of the original felspar.

Calcite and quartz are granular and secondary; dolomite is common in some of the much-sheared chloritic schists. Primary quartz, forming micropegmatite, has been seen in one or two of the more massive rocks. Hence some of these were originally quartz diabases. The epidote, often very abundant, is granular, bright yellow, and pleochroic; colourless zoisite also occurs. Ilmenite forms skeleton crystals or networks, as in many diabases, and is very generally altered to granular sphene or leucoxene. A yellow or greenish-yellow kind of biotite is rather frequent in these rocks, and though its origin is not entirely clear, seems to be mostly secondary. It occurs with chlorite, usually in rocks containing little or no hornblende, and though sometimes in well-defined plates is more often scaly and lamellar like the chlorite which it accompanies. Apatite may be very common, especially in the coarser-grained rocks, forming large hexagonal prisms. The other minerals, pyrite, magnetite, limonite, sericite, and kaolin, need no special description.

Three types of epidiorite occur in this area, and may be distinguished from one another by more or less important differences in structure, mineralogical composition, and geographical distribution. The first group includes rather coarse-grained, often nearly massive rocks which show remains of ophitic structure, are not vesicular, and represent altered phases of diabase or dolerite. The second group consists of finer-grained rocks, not uncommonly schistose or foliated, and very frequently vesicular. Many of them

are porphyritic. These rocks are identical in all important respects with the pillow lavas of the Tayvallich district. The medium-grained epidiorites which form dykes in the quartzite and schists of Jura and Scarba present many features which distinguish them from both of the above groups, and form a class apart.

In the coarse epidiorites of Kilmartin, Craignish, and the north side of the Crinan Loch (Plate VIII., Fig. 3) the hornblende in section forms large pale-green or dark-green plates often fringed by acicular crystals. Granular yellow epidote is very common, mingled with hornblende, chlorite, or felspar. Biotite is not frequent in these rocks, but chlorite is more common, though less characteristic than hornblende. The felspar is sometimes much crushed and granulitized, or replaced by aggregates of sericite, epidote, quartz, and other secondary products, but is often surprisingly fresh and well preserved. It has the properties of acid oligoclase or albite oligoclase, sometimes approaching closely to albite in its optical reactions. This is a distinctive feature of the rocks of the second group and of many pillow lavas and spilites in different parts of the British Isles. Hence the connection between these coarse epidiorites and the pillow lavas cannot be doubted. Calcite and other carbonates are less common in these than in the vesicular epidiorites; their place seems to be taken largely by the abundant epidote. Secondary quartz is frequent, and this mineral occurs also as a primary ingredient of interstitial micropegmatite in a few specimens. The ilmenite in the form of large skeleton crystals and networks is always conspicuous in the slides. Apatite also is abundant, its crystals being sometimes more than a millimetre long; they are often broken and dislocated, but may be intact, and this, together with the perfect preservation of the ilmenite skeletons, shows that internal movement has often taken place only on a restricted scale, in consequence, no doubt, of the comparative massive character of these thick diabase sills. The changes through which they have passed are principally the uralitization of the augite, alteration of ilmenite to leucoxene, and the formation of abundant epidote and chlorite. In one of this group of rocks from the summit of Creag Bhreac, one and a quarter miles north of Kilmartin, a little of the original augite remains; it is of a pale brown colour, and is surrounded by clear green uralitic hornblende. The ophitic structure in this rock, as in most of the group, is perfectly apparent. Among the uralite secondary greenish-brown biotite occurs sparingly. In every other specimen which has been examined microscopically the pyroxene has all disappeared, but large masses of pale green, partly fibrous, hornblende retain in some measure the outlines of the original augite, and enclose lath-shaped felspars more or less altered and replaced by new minerals. From this it is obvious that the group consists of modified phases of ophitic diabase rocks which were presumably of intrusive origin. Only rarely is the ophitic texture effaced by movement and a foliated character assumed where there has been a considerable amount of crushing. Chlorite schists are then produced containing epidote, sericite, and carbonates.

One rock of the epidiorite series is worthy of special description as showing in an unmistakable manner the propensity of these rocks in this part of Argyllshire to contain abundant alkali felspars. The specimen comes from Cnoc na Faire, on the south border of the sheet, near the shore of the Sound of Jura. It forms an intrusive sheet which is distinct in its general appearance from most of those which occur in this neighbourhood, and in the hand specimen is of a grey colour, schistose (the foliation planes being covered with films of black mica), and obscurely porphyritic. The phenocrysts are microperthite, and have suffered peripheral granulitization, being sometimes reduced to ellipsoidal phacoids. The matrix has a parallel structure which seems to be partly an original fluxion structure and partly the result of crushing. It consists of parallel and curving streams of small felspar laths; most of these are albite or albite-oligoclase, but some orthoclase may also be present. Their sections are so well shaped that the igneous, porphyritic character of the rock is quite evident. Mingled with them are scales of biotite, a little muscovite, a very small amount of chlorite, iron ores, some carbonates and quartz. The rock contains no hornblende; its special features are the great preponderance of alkali felspar and the scarcity of ferromagnesian minerals. In these respects it approaches the bostonites; alternatively it might be classified as a syenite-porphyry or "soda felsite." Yet there seems no reason to doubt that it is a member of the epidiorite succession, differing from the others in its strongly leucocratic character.

The second, and, so far as the collections show, the more abundant type on the mainland of Argyllshire, is finer-grained and usually vesicular. Foliation is more perfect in this group; this is probably a consequence of the weaker character of the rocks and the abundance of cavities filled with soft minerals such as calcite, but the parallel structure may also be partly due to original fluxion. Epidote and hornblende, though occurring in many of these rocks, are less frequent than in the previous group. Biotite and chlorite prevail. The felspars are largely oligoclase and oligoclase-albite. Ophitic structure has not been observed in this series, but on the other hand many of them are porphyritic, and where they have not been much crushed the larger felspars may still show idiomorphic outlines. (Plate VIII., Fig. 4.) Quartz and carbonates, with chlorite, are the substances which fill the steam cavities and form rounded or lenticular pale-coloured areas which show prominently against the dark ground-mass of rock. There is every reason to believe that these rocks represent the pillow lavas of Tayvallich, which present many similarities with them in structure and in composition.

The microscopic sections of these vesicular epidiorites vary somewhat in appearance according to the amount of crushing which the rocks have undergone. The plagioclase felspar is the most conspicuous ingredient, and is the least altered of the essential primary minerals. Its outlines are more or less rectangular, and

the crystals are often arranged in a parallel manner. Large phenocrysts occur, but not universally; they may be two millimetres in diameter. Most of the crystals are much smaller than this; the larger ones may be broken by movement, and the others have frequently their angles rounded or removed. Carlsbad twinning is very uncommon, but albite and pericline twinning are frequent. These felspars have a low refractive index and specific gravity; they belong to oligoclase and oligoclase-albite, and some have nearly the properties of pure albite. This important feature has been remarked on by Dr. Teall* as characteristic of the pillow lavas (spilites) of the Silurian rocks of the south of Scotland, and is repeated in pillow lavas of various parts of Britain.

No augite has been seen in any of these rocks from this sheet; it is entirely replaced by chlorite, biotite, and hornblende. Hence it is impossible to say whether the original structure was ophitic, or whether there was in some instances a certain amount of vitreous or hemicrystalline ground-mass, as is rendered probable by the abundance of steam cavities. The green chlorite and greenish or brownish biotite, intimately mingled, fill up the interspaces between the felspars. Hornblende is not very common in these epidiorites; when present it is very pale green and acicular or fibrous: not unfrequently it is represented by pseudomorphs of calcite and chlorite. Secondary carbonates (mainly calcite) and quartz occupy most of the vesicles, and impregnate the rest of the rock. There is no evidence for primary quartz or olivine. Thin plates of ilmenite, weathering to leucoxene, are invariably present the larger open networks of this mineral seen in the coarser epidiorites are typically absent. Apatite occurs, but only in small crystals. Epidote is comparatively scarce, and forms small granules, as distinguished from the conspicuous yellow grains found in the rocks of the first group. Sericite and kaolin after felspar, pyrites, and limonite enter largely into the composition of some specimens.

Two of the epidiorites of this Sheet have been analysed by Mr. E. G. Radley in the Geological Survey laboratory. The first (13040) is one of the vesicular or pillow-lava type, and was taken at a point three-eighths of a mile east-south-east of Ardifuar, on the north side of Crinan Loch. The second (13041) belongs to the coarsely crystalline or diabase type; it comes from an epidiorite mass on the hill-top on the north-east side of Ardifuar. With these we quote for comparison analyses of the lowest pillow lava on the west side of the Tayvallich peninsula (12453), Argyllshire, and of a pillow lava from Devonport Workhouse Quarry, Devonshire (E4947), also by Mr. Radley.†

* *Memoirs of the Geological Survey of Great Britain*: The Silurian Rocks of Great Britain, vol. i., p. 85.

† W. A. E. Ussher (with contributions by John S. Flett). "The Geology of Plymouth and Liskeard" (*Mem. Geol. Surv.*), p. 97 (1907).

	13040	13041	12453	E4947
SiO_2	49·74	42·36	51·31	40·55
TiO_2	2·05	4·95	1·92	2·95
Al_2O_3	14·85	14·09	12·67	16·65
Fe_2O_3	1·04	2·17	0·54	1·01
FeO	10·61	10·48	7·99	9·46
MnO	0·39	0·28	0·45	0·20
(CoNi)O	n.f.	0·09	? tr.	0·07
BaO	n.f.	n.f.	n.f.	n.f.
CaO	6·17	10·05	8·17	6·06
MgO	2·48	5·70	2·19	5·20
K_2O	0·53	0·80	0·54	0·27
Na_2O	4·52	3·26	5·21	4·76
Li_2O	? tr.	tr.	? tr.	? tr.
H_2O (105°C)	0·05	0·12	0·04	0·27
H_2O (+105°C)	3·37	2·92	2·31	3·89
P_2O_5	0·62	1·02	0·90	0·73
FeS_2	0·13	n.f.	0·30	0·18
Fe_7S_8	...	...	0·17	...
CO_2	3·18	1·73	6·15	7·85
Cl	tr.	tr.	...	n.f.
Total	99·73	100·02	100·86	100·10

A comparison of the analyses of the two pillow lavas (third and fourth columns) with the porphyritic rock from Ardifuar shows that the chemical peculiarities which characterise the spilites are well developed in all three.* They are rocks with relatively low silica percentage and rather high alkalies (5 to 6 per cent. of soda and potash). In the specimen from Ardifuar (13040) there is much calcite and sphene, and if we deduct the lime required to combine with the titanium dioxide and carbonic acid to form these minerals, very little is left over to form anorthite felspar. The rock contains 5·05 per cent. of soda and potash, which shows that about 40 per cent. of the whole mass consists of albite and orthoclase. In fact, the results of the analysis show perfectly clearly that the vesicular epidiorites of the Crinan area were pillow lavas of the same kind as those of Tayvallich, twenty miles farther south, and of the Upper Devonian volcanic rocks of eastern Cornwall. The second analysis shows that the coarsely crystalline or diabase type has less marked chemical peculiarities than the lavas. It has high alkalies for a dolerite, but is richer in lime than the spilites, owing to the abundance of epidote. The abundance of titanium dioxide in this rock is remarkable. It is also unusually rich in phosphoric acid. These two rocks are represented in Figs. 3 and 4 of Plate VIII.

The epidiorites of the third group occur as dykes in the islands of Jura and Scarba. The method of occurrence of these rocks signalises them as a distinct series from any Highland epidiorites

* Flett, *loc. cit.*

which have hitherto been described. Their petrographical characters also are distinctive, though they bear a great resemblance in general aspect to many of the rocks included in the two previous groups. Often they have been much crushed locally, but it is believed that they are later than the main period of folding in this district. Hence they cannot be the same as the volcanic lavas and intrusive sheets which are intercalated in and folded with the sediments of the Loch Awe series.

Lithologically they are pale green, usually massive or only slightly foliated, and neither porphyritic nor vesicular. Under the microscope they show that, while there has been very complete alteration of their minerals, the ophitic structure is still clearly preserved. From this it may be inferred that the original rocks were dolerites or diabases. They contain many pseudomorphs after felspar, consisting of quartz and sericitic mica, and filled with small highly-refracting grains of epidote; these pseudomorphs have a broad or narrow rectangular outline like the felspar "laths" of the dolerites. They lie in shapeless masses of green, reedy hornblende, chlorite, and green or brownish biotite; these represent the augite which once enclosed the felspar. Unweathered felspar is rare, and fresh augite has not been found. The biotite may be largely secondary like the chlorite, but there is a chance that some of it is primary; it resembles that which occurs in the vesicular epidiorites of the mainland. The hornblende is usually pale green and feebly dichroic. It rarely forms good crystals, but occurs as irregular plates of masses of tangled fibres. Chlorite is very common, and with hornblende gives the rocks their pale green colours in the hand specimens. The epidote rarely forms large yellow grains. Networks and plates of ilmenite, changing to leucoxene, grains of calcite and apatite, and patches of secondary quartz are always present in the slides. It is not clear whether any of the quartz is primary. Where any of the felspar is sufficiently well preserved to show its twinning, as occasionally happens, the mineral is rendered turbid by small particles of chlorite, calcite, and hornblende. J. S. F.

CHAPTER VI.

Folding and Metamorphism.

Folding.—The older rocks shown on the present map everywhere bear evidence of great lateral compression, which has thrown the strata into a series of sharp folds and otherwise modified them. The structures here exhibited are of particular interest since the region lies athwart the great central belt of pseudo-fan-structure, whose axis traverses Argyllshire in a N.N.E. and S.S.W. direction. The axial line crosses the map from a point a little to the north of Kilmartin to the southern margin near the head of Caol Scotnish, the most northerly branch of Loch Sween.† Along this line the axial planes of the folds are vertical. Passing outwards from this central line, the axial planes on each side dip towards it, the general angle of inclination diverging more and more from the vertical as the distance from the centre of the belt increases. The dominant structure induced upon the rocks is strain-slip cleavage, which has followed on a cleavage the planes of which lie more or less parallel to the axial planes of the folds. Consequently the most obvious structures all dip towards the central axis where the structures are vertical.

A glance at the map is sufficient to show that over the greater part of the area the amplitude of the folds cannot be great, since the rocks of sedimentary origin are, for the most part, arranged in broad belts, with only a slight interweaving of the outcrops of the different groups along their mutual margins. It can be demonstrated that, with the exception of the quartzite group as developed on Scarba and Jura, the groups of sedimentary rocks shown on the map are individually of no great thickness, and most of them indeed quite thin, so that their lateral extension is almost entirely due to repetition by folding.

In one area, however, near the west coast south of Crinan, Mr. Bailey (p. 42) is of the opinion that overfolds have been produced of such magnitude and lying at such low angles, that the overthrown strata have been again overfolded and involved in the outward advancing portions of the pseudo-fan.

Another point also made clear by a brief inspection of the map is that the individual folds do not extend indefinitely in the direction of their longer axes, but often pitch out at both ends, and are succeeded along the same line by folds of an opposite character.

† Macculloch calls attention to this line of vertical dip, which traverses the country between Loch Sween and the western coast, and notes that on each side of it the prevailing dip is inwards towards it. (*Description of the Western Isles of Scotland*, 1819, vol. ii., p. 288.)

Thus, in the Kilmartin region, one can, by a short traverse along the apparent strike, pass successively over each member of all the groups of sedimentary origin.

Consequently on the tectonic structures above described, the various groups of sedimentary rocks with their accompanying sills of epidiorite, even though vertical or highly inclined, convey the impression on the map of being horizontal or inclined at a gentle angle.

As a further result of the movement, these widespread sheets of corrugated strata have been thrown into broad and gentle undulations whose longer axes run parallel to those of the minor folds. The area under consideration thus displays a central compound anticline upon which the oldest sedimentary rocks are exposed flanked on either side by a wide compound syncline containing the younger members of the sedimentary series.

The axis of this great compound anticline runs in a N.N.E. and S.S.W. direction through the promontory of Craignish, striking the north side of Loch Melfort near the head of Bagh na Dalach (Dogfish Bay), and extending southward from Craignish Point through Ruadh Sgeir. It will be seen that this axis does not coincide with the Kilmartin axis of vertical structures, but lies several miles to the west of the latter. The overfolded strata and cleavage-planes along the Craignish anticlinal axis all dip E.S.E. towards the Kilmartin axis of foliation.

The following diagrammatic section drawn from the Garvellachs across the area to the west side of the Kilmartin valley will serve to illustrate this point. The corrugated line represents the junction between the Craignish phyllites and the Easdale slates, the undulating line, the present rock surface, and the horizontal line the sea-level. (Fig. 6.)

It will be seen from the above section, from a study of the map, or better still from an examination of the ground, that this great structural belt which traverses the area does not altogether conform to the true definition of a fan, in which the axis should coincide with that of a compound anticline. In all other respects the structure is that of a fan.

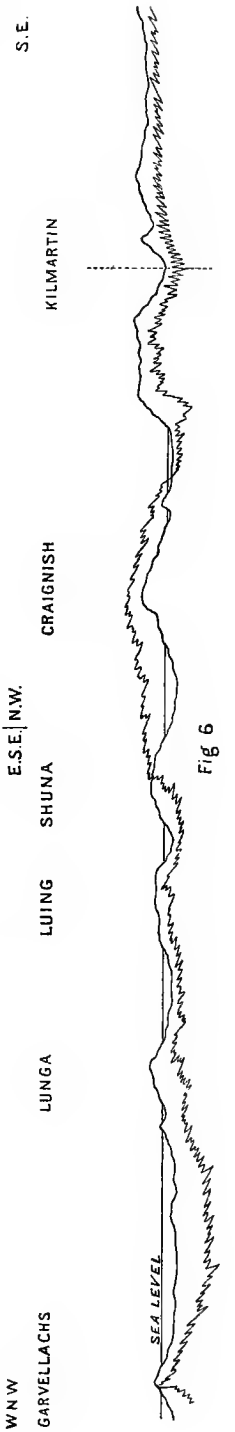


Fig 6

To anyone acquainted with the geology of the Central Highlands, perhaps the most obvious feature of this map is the abnormal strike of the metamorphic rocks, which over the eastern part of the sheet is either N.N.E. and S.S.W. or north and south. Throughout the greater part of the Central or Southern Highlands the prevailing strike is E.N.E. and W.S.W. The present area is only part of a much more extensive belt which shares in this abnormal strike and stretches southwards from Lorne to near the Mull of Kintyre, where the strike becomes normal once more. On each side of this belt the rocks rapidly resume their ordinary direction. This deviation of strike appears to be due to a wrench analogous to that which accompanies the great N.N.E. and S.S.W. wrench faults that traverse the Highland rocks, and of which the Loch Tay fault is perhaps the best known example.

This movement certainly took place earlier than Lower Old Red Sandstone times, as it does not affect the Lorne Volcanic Plateau which lies athwart the belt, and may have followed immediately upon the general movements of compression which foliated the rocks of the region.

The distribution of the epidiorite dykes on Jura and Scarba may have some relation to this torsional movement, as they occur at a point where, on the assumption of such a wrench, an area of extension of the materials and an opening up of weak structures would theoretically occur.

The position of the dykes relatively to this part of the structure may in this case be only due to a coincidence; but the fact that the dykes are foliated either throughout or along the edges parallel with their margins shows that even after their introduction movements of adjustment were still going on.

Metamorphism.—The grade of metamorphism is nowhere high except where close to the later granite masses contact alteration has been superinduced upon the earlier regional metamorphism due to compression. Everywhere the signs of mechanical deformation are more apparent than those of reconstruction, and the clastic nature of a large proportion of the rocks of sedimentary origin, and the original crystalline texture of most of the igneous rocks, are still quite obvious.

As might be expected, the compression of a congeries of materials of such different resisting powers as shale, limestone, grit and conglomerate, basic lava, and intrusive rocks, as well as the aureoles of hardened sediments surrounding the latter, has given rise to a most varied set of phenomena. The main structure set up in the argillaceous rocks is a strain-slip cleavage which is best exemplified in the Craignish phyllites. It has, however, been shown by Mr. Muff that the strain-slip cleavage has been preceded by a true slaty cleavage, the planes of which are more or less parallel to the axial planes of the folds. The chief new minerals set up are sericite and chlorite.

The dark argillaceous rocks of the Easdale slate group have yielded rather less to the strain-slip cleavage than the Craignish phyllites, and hence are of economic value for the manufacture of

roofing slates. The best slates are studded with cubes of iron pyrites.

The sandy and gritty strata have suffered still less from movement than the argillaceous rocks. Not only do the former lie in larger and gentler folds than the phyllites, but the individual beds are less traversed by minor planes of movement. The planes of disruption are also more localised and much further apart, thus allowing the thrust movements to affect considerable masses, which move *en bloc*. Except along these crush-lines, only the finer grains are crushed, and in some cases granulitised, the larger grains of quartz and felspar either escaping altogether or showing only a peripheral deformation. In the case of grits with a calcareous matrix, the movement is almost entirely confined to the matrix, the included grains or pebbles being left uncrushed, although they may be orientated by the movement, and have their longer axes arranged in the same general direction as the strain-slip cleavage in the neighbouring softer strata. This is most apparent in the case of the boulder-beds in the Garvellachs, where the original crystalline structure of the igneous boulders is preserved quite intact. White mica is set up along with the other minerals along the planes of movement. In conformity with the known behaviour of calcite when confined under great pressure, the purer limestones have for the most part suffered deformation without disruption and become crystalline marbles.

The usual phenomena of thinning out of the weak limbs of the folds and flow into the areas of least pressure are present. In the thin-bedded impure carbonaceous strata, sericite is occasionally developed, and the flakes of this mineral, along with grains of sand and carbon, orientated in a direction more or less parallel to the cleavage planes.

Turning to the epidiorites, we find that the finer-grained (lava-form) rocks have in almost every case yielded to the movements and become hornblende-epidote-chlorite schist with more or less carbonate, chiefly calcite, while in some cases the strain-slip cleavage is so perfect as to cause them to simulate the appearance of schist of sedimentary origin. These lava-form rocks are found in a least deformed condition in the phacoids contained in the pebbly limestone, which seems to have preserved them from the effects of the movement. The greatest amount of movement and alteration seen in the coarser intrusive rocks has taken place along their fine-grained margins, the more unyielding cores and the aureoles of hardened sediments on either side of the intrusion escaping with only slight deformation. The margins have for the most part been affected similarly to the finer-grained lava-form rock. Some of the thinner sills are, however, foliated throughout. Where porphyritic phenocrysts of plagioclase are present in the lavas or sills, the finer-grained ground-mass is often in a granulitic condition, while the phenocrysts have remained in the cataclastic stage. It is consequently not unusual to find disrupted fragments of an original plagioclase crystal floating in a chloritic hornblende schist. In the more porphyritic intrusive sills every stage in the

Crags on S.E. shoulder of Creag nam Fitheach, 3½ miles north of Kilmartin.
Phacoids of epidiorite in pebbly limestone matrix (p. 61).

production of such a schist can be studied. There is a strong body of evidence to show that many of the lava-form rocks and some of the sills had been in part epidotised before the initiation of the movements that brought about the metamorphism. As has been stated elsewhere, the fine-grained dykes that occur in Jura and Scarba, and were intruded after the greatest period of compression, are generally foliated along their margins. B. N. P.

Crush-Conglomerates.—The present area affords innumerable examples of every stage in the production of pseudo- or crush-conglomerates.* The most favourable conditions for their manufacture exist where thin beds of a comparatively unyielding nature, interstratified with thicker masses but of weaker strata, have been subjected to lateral pressure. The incipient stages result from the interbanding of more finely argillaceous rocks with less yielding material, such as sandy and calcareous bands. The harder bands being traversed by fewer gliding planes, are fractured at more or less regular intervals, and the fragments become isolated by the slates or phyllites, each band forming an irregular double row of curved lenticles. This is a common phenomenon in the Craignish phyllites. A further stage is reached when the separated particles have been more or less rolled into phacoids, which are arranged with their longer axes in the direction of the movement along the cleavage planes. The best examples of this structure are afforded by the massive pebbly limestone where interbedded with shaly and sandy layers, and bounded on one side by epidiorite lavas or sills.

B. N. P.

The crush conglomerate involving the pebbly limestone is particularly well displayed on Creag nam Fitheach, a hill that rises immediately to the east of the head of Loch Craignish. (Plate VI.)

The section shows limestone in contact with an epidiorite sill. The junction of the two rocks is intricately interfolded, portions of folds of epidiorite from a few inches to a foot or more in thickness being packed together at a high angle in a limestone matrix. In addition, lenticles, usually of epidiorite, but sometimes of limestone, are seen completely isolated. The limestone, however, has generally played the part of a plastic matrix in which these isolated fragments of epidiorite have arranged themselves. At the south-eastern corner of the hill a bed of this nature, from two to six yards thick, rests more or less horizontally upon the limestone. In this bed the long axes of the folded limbs and detached fragments are in alignment with the strike of the foliation and of the folding axes of the district, so that we have, in cross section, a series of closely-packed lenticles within a limestone matrix. The junction, however, of this composite mass with the underlying limestone is not sharp; for some yards in from the epidiorite mass the limestone contains igneous blocks, some of

* Crush-conglomerates from this neighbourhood were first described by Mr. J. B. Hill in his paper "Crush-Conglomerates of Argyllshire," *Quart. Journ. Geol. Soc.*, vol. lvii., 1901; and later by Messrs. Peach, Wilson, Muff, and Bailey, in Summaries of Progress for 1901-1902.

which are well rounded, while just below the composite bed solid blocks of epidiorite are seen in the limestone which have not yet been drawn out into lenticles. On the north-western corner of the hill the limestone contains boulders of epidiorite, perfectly rounded, and ranging in size from a foot in diameter downwards. Boulders of grit are also seen in the limestone, but these are evidently derived from a grit band which is sometimes seen in contact with the limestone.

Many other instances might be cited where similar structures have been set up near the junction of limestone and epidiorite. These phenomena, however, are not confined to those two rocks. Near Creagantairbh, nearly two miles N.N.E. of Kilmartin village, a similar pseudo-conglomerate is seen in a band, five or six feet in thickness, of fine quartzose rocks between coarse massive grits. The fine-grained rock, which has almost the appearance of hornstone, has been folded, fractured, and the fragments isolated, the various stages of crush-conglomerate manufacture being so apparent as to leave no doubt that we are dealing with a process of mechanical deformation.

Similar structures have also been detected within the epidiorites themselves, although, owing to the comparatively homogeneous nature of the material, they are not so conspicuous, and consequently may easily escape observation. Fragments of epidiorite may, however, be seen enclosed here and there in the main mass, as well as the remains of both crests and limbs of folds which have been torn from their original position. J. B. H.

Another good example of the structures described as "crush-conglomerates" occurs in a cliff 1200 yards north by east of Salachary. Two undulating bands of phacoidal masses of epidiorite, commonly between six inches and one foot in length, and with highly-inclined long axes, cross the face of the pebbly limestone cliff. These oval masses of epidiorite do not possess the vesicular coating of the "pillowy" bodies which occur in the "lava-form" epidiorites. Their formation by folding and shearing is rendered practically certain in this case by reason of the presence of a third, but shorter, belt of phacoids of black slate embedded in the limestone, since the black slate phacoids can only be accounted for by the disruption of a bed of black slate.

H. B. M.

Thrust Planes. — Although the grade of metamorphism throughout the area is low, there is evidence of a gradual increase in degree of alteration from west to east.

On the west side of Scarba, for instance, the original clastic micas in the sandy shales of Zone V. are easily visible to the naked eye.

As we are here dealing with the highest members of the whole series found in the area and those which are absent from the mainland, the unaltered condition of the Scarba rocks might at first sight be attributed to less load in that part of the region. That this phenomenon is regional and not entirely due to decrease in load is, however, shown by the fact that the rocks of the Gar-

vellachs, which lie at the base of the whole quartzite series, are equally unaltered.

Evidence bearing more on the amount of load is found in the fact that on the mainland—except in the area south of Loch Crinan, where the quartzite has in places been affected by undoubted thrust-planes —only small strain-slip thrusts have been observed, leading to the supposition that this part of the region was under a considerable amount of load. In Scarba and the west of Jura thrust-planes are numerous,* and are accompanied by "staving" of the quartzites and mylonisation and granulitisation along the lines of movement. Some of these thrusts are, however, certainly later than the main movement of compression, for on Scarba they affect the peculiar epidiorite dykes which cut the folded and compressed strata.† The quartzites on Garbh Eileach, one of the Garvellachs, are in places traversed by a similar series of small thrust-planes, but in this case there is unfortunately no means of fixing the date of the movements. At the time that the quartzites thus acted as a brittle body the rocks could not have been under any great load. In fact, the amount of strain-slip cleavage in the area to the east seems to show that nowhere can this have been the case.

B. N. P.

* Summary of Progress, 1900, p. 49.
† Summary of Progress, 1901, pp. 75-76.

CHAPTER VII.

Rocks of Lower Old Red Sandstone Age.

VOLCANIC AND SEDIMENTARY ROCKS.

Country North of Loch Melfort.—This area is almost entirely occupied by andesitic lava-flows of Lower Old Red Sandstone age. They constitute a continuation of the volcanic plateau of Lorne which is for the most part comprised within Sheet 45 to the north-east, and extends also into Sheets 37 and 44. The margin of the series forms a well-marked line of crag, well seen to the north of the upper part of Loch Melfort. On the north-east side of Kilchoan Bay this line is seen to form part of the steep ground above the shore of the loch. It then strikes northwards and forms the northern boundaries of the curious hollow known as An Coire. To the east of this hollow it rises in a well-marked line of feature, running in a north-easterly direction and bending round gradually to the east to the Pass of Melfort. From here it runs almost due east and then south, and occupies the slopes above the north end of Loch Pearsan.

The contact with the older schists everywhere shows the usual well-marked unconformity. The andesites here rest immediately upon the denuded edges of the schists without the intervention of any material of sedimentary origin. The actual line of junction is often obscured by *débris* of rotten andesite from the crags above, but when exposed there is usually a thin breccia, of local origin, between the schist and the lowest flow. The old surface upon which these flows were poured out was evidently hilly and uneven, and broken into ridges and hollows. This is shown by the gradual rise of the boundary line of the volcanic series from near sea-level, on the east side of Kilchoan Bay, to a height of over 800 feet in the area about An Coire; while the occasional occurrence of inliers at some height within the andesites serves to mark the site of some of the more prominent ridges of the older rocks.

The different flows of andesite are often well indicated by the conspicuous lines of escarpment which form so characteristic a feature of this area, and the upper surface of the flows is often shown by the slaggy and brecciated condition of the rocks forming the upper lines of crag along these features. The escarpments trend in a general N.N.E. and S.S.W. direction and follow the strike of the lava-flows, the general dip of the series being in a N.N.W. direction. The dip is seldom more than 15°, though occasionally higher angles have been noted.

On the whole the lava-flows of this area are exceedingly uniform in composition. They may all be assigned to the more basic division of the andesites, while some approximate perhaps more closely to the basalts. There is a complete absence of acid types of andesite or of any felsitic types of flow, such as those which characterise higher horizons in the more central part of Lorne. The majority of the flows of the area consist of dark purple and sometimes greyish andesites, sometimes compact and sometimes highly vesicular, the latter character being often observed in the upper parts of the flows. The compact varieties are generally the fresher, and often show a well-developed flow-structure, the rock tending to split up into thin plates. Porphyritic crystals of felspar are only rarely seen, though small specks of a reddish-brown mineral (? iddingsite) are often very common. The vesicular varieties are usually much decomposed, and weather in various purple and reddish shades. Some of the flows are evidently closely allied to basalt. Thus, one of the more basaltic types of flow may be traced for some distance to the north-west of Melfort. It forms the face of an escarpment for a distance of about a mile, on the south-east side of Cruach Dorch nam Fiann and Cruach nam Fearna. Other exposures of this basaltic type are to be seen further to the north-west at Loch an Fhuarain, and again about half a mile north of Melfort House. It is a hard, almost black, massive rock, and closely resembles basalt.

Under the microscope a specimen from this basic flow, from half a mile north of Melfort House, shows [10356] numerous more or less idiomorphic olivines, mostly quite fresh and only occasionally altered into serpentine, in a matrix of small plagioclase laths, augite grains, and magnetite. There are no plagioclase phenocrysts, and the rock is evidently closely allied to the olivine-basalts. Another specimen from two miles north-west of Kilmelfort [10357] shows similar characters to the above, but is finer-grained. The olivines are smaller but very numerous, and show good idiomorphism, and are often associated with flakes of a yellowish micaceous mineral (? iddingsite). The ground-mass is mostly composed of small plagioclase microliths with a tendency to fluidal arrangement, pyroxene granules, and iron-ores. There may also be a certain amount of undifferentiated interstitial matter. These rocks are certainly most remarkably fresh for Lower Old Red Sandstone lavas, and there is no other instance in the Lorne area where rocks have been found containing unaltered olivine, though basic lavas containing numerous pseudomorphs after that mineral are very common.

Fragmental volcanic rocks have only occasionally been met with in this area. There are no coarse agglomerates and no tuffs such as characterise the more central region of Lorne, described in the Explanation of Sheet 45. A band about 20 feet in thickness of a fine-grained reddish ash occurs at the base of the escarpment which forms the south-east side of Druim Barr na Coille, three-quarters of a mile N.N.W. of Melfort House, and is again seen, intercalated with the basic flows, to the south-east of Cruach Dorch

nam Fiann. A thinner band of similar material may be seen underlying the andesite crags of the Pass of Melfort. This ash consists of small, more or less angular, fragments of basic andesite, which have assumed a reddish colour from decomposition.

Seil Island.—The andesites of this area are essentially the same as those of the north-east corner of the map, and do not call for any detailed description. There is a strong tendency here also to the formation of lines of north-east and south-west escarpments, the general dip of the lava-flows being to the north-west. (Plate I.)

At the southern and eastern margin of the series the andesites rest directly upon the upturned edges of the black slates, without any intervening conglomerate, though occasionally some basement breccia may be seen. On the west shore, north of Easdale, we find red shales, grits, and conglomerate, but these sediments are apparently not at the base of the lava-flows of this area, as andesite is again seen immediately beneath them. These beds are well exposed in the small bay on the north side of Dun Mor, and lie mostly below high-water mark. They dip in a north-westerly direction at an angle of from 10° to 20°, and consist of red shales and grits overlain by a few feet of conglomerate. The shales rest upon a highly vesicular andesite, and the conglomerate is overlain by a dark, compact, rather basic andesite, well exposed on Am Biorain. Very similar shales and gritty beds are again seen at the top of the steep slope on the south-east side of this bay. All the andesitic flows of this area seem to belong to basic types, and are sometimes dark and compact, or purple and highly vesicular. Brecciation of the flows is often well shown, the resulting rock sometimes showing a strong resemblance to an agglomerate. The best sections of the andesites are undoubtedly found along the fine series of crags that form the basal portion of the series, and extend from An Grianan to Dun Mor, while the dark grey compact type is well exposed on Am Biorain, to the north of Dun Mor. H. K.

Lunga Island.—Two small outliers of conglomerate occur on the Rudha Fiolain, the northern part of Lunga, where that island is cut up by a series of channels and becomes an archipelago of islets at high water. On the north side of the most northerly of these channels, a conglomerate, made up of well-rounded quartzite boulders, is pierced by a lamprophyre sill. A short distance further to the south another small patch of similar conglomerate protrudes through the raised beach deposits which cover the greater part of the Rudha Fiolain.

No andesite pebbles were observed in the conglomerate, but the fact of the latter being composed of the quartzite of the island shows that the conglomerate is younger than the schistose rocks, while the intruded lamprophyre proves that it is earlier than the later stages of the Lorne volcanic episode.

These patches of conglomerate, therefore, probably represent fragments of the basement members of a widespread series of Lower Old Red Sandstone sedimentary and igneous rocks, and are

intermediate in position between the Lorne Plateau in the north and Glas Eilean, far to the south in the Sound of Islay.* B. N. P. .

Intrusive Igneous Rocks.

DIORITES AND GRANITES.

Numerous intrusive masses, mainly consisting of diorite, have been mapped in the neighbourhood of Kilmelfort and in the area on the south side of Loch Melfort. The area occupied by these intrusions extends from Kilmelfort in a southerly direction to the southern slopes of Tom Soilleir and Beinn Chaorach. Throughout this comparatively small area there are scattered a number of intrusions, varying greatly in size and accompanied by numerous small dykes and sills of porphyrite and felsite. These intrusions bear such a strong resemblance to one another as to suggest that they are merely the subsidiary offshoots and protrusions of a much larger underlying mass, and the relatively large area of contact-alteration seen in the surrounding phyllites and calcareous schists gives considerable probability to this view.

The largest of the intrusions occupies the highest portion of the ground about Tom Soilleir. It is a roughly oval-shaped mass, being elongated in an east and west direction. The rock is a medium-grained grey diorite, in which flakes of biotite are usually conspicuous to the naked eye. It is fine-grained at the margin and becomes decidedly coarser towards the more central part. The exposures usually show a good deal of shattering and weathering, the crags often weathering out into more or less rounded forms, and the majority of the hill-features are smooth, rounded, and covered with grass and thin heather, while the highest portions of the ground form peaty flats with occasionally protruding rocky knobs. The ultimate stage of the weathering is a fine felspathic micaceous sand, which covers large portions of the area, and often encloses rounded boulder-like lumps of partially disintegrated diorite.

The contact between the diorite and the altered schist which surrounds it is sometimes clear and well-defined, but is often, on the other hand, of an exceedingly complex nature, the hornfels being traversed by numerous small veins and strips of the igneous rock. Frequently, again, large portions of the schist have been broken up and floated off by the intruding magma, which in this way has produced a marginal breccia of hornfels fragments in a fine-grained dioritic matrix. Occasionally the diorite appears to pass at its margin into a variety of porphyry or porphyrite, but this occurs rather in connection with the smaller intrusions than with the larger masses, where the marginal facies is seldom markedly porphyritic. Dyke-like intrusions and irregular masses of a highly felspathic and more acid material are also frequently associated with the diorite, and may occur along the margin or in

* *Memoirs of Geol. Survey*—"The Geology of Islay," chap. viii., p. 55, 1907. Summary of Progress, 1897, p. 64; 1898, p. 75.

the more central portions of the mass. Owing to the usually highly decomposed condition of these acid rocks it is not easy to see their exact relations to the diorite. It does not appear, however, that there is any passage between the two, but the more acid rock probably represents a slightly later intrusion from the same magma. Sills of a similar material are also sometimes met with in the surrounding schists. Both in the schists, however, and in the diorite, these rocks are usually so decomposed that it is difficult to examine them at all satisfactorily. They seem to consist [10346] mainly of more or less idiomorphic plagioclase crystals, the interspaces between which show a small quantity of ground-mass consisting of microcrystalline plagioclase, alkali-felspar, and quartz. Ferromagnesian constituents appear to be almost entirely absent. There is usually also a considerable quantity of pyrites in the more decomposed portions, and a pale mica, probably due to the alteration of the felspar. Small felspathic veins are also sometimes seen in the diorite.

The normal type of rock, which constitutes the greater portion of the larger intrusive masses, is a medium-grained grey diorite with conspicuous biotite. It does not contain sufficient orthoclase or quartz to be ranked with the granites, though some varieties occasionally show affinities to these more acid types. A specimen of the coarser phase of the Beinn Chaorach mass, which lies to the west of that of Tom Soilleir, was collected at a point about three-quarters of a mile east of Asknish, and may be taken as showing the normal composition of these rocks. Under the microscope [10344] one notes a large proportion of idiomorphic plagioclase. This frequently shows a zonal structure, and twinning on the pericline plan in addition to the normal twin-lamellæ. The other constituents comprise a pale green hornblende, usually in rather irregular plates and grains, though sometimes showing signs of idiomorphism, biotite, and some interstitial alkali-felspar and quartz. The biotite is of the deep reddish-brown variety, with strong dichroism, but never shows idiomorphism. It is in ragged plates which are moulded upon the plagioclase, and is, therefore, of later formation than that mineral. In the finer-grained phases the diorite often becomes slightly more basic, and shows some pale augite in addition to the hornblende. This is seen in some of the fine-grained parts of the large mass of Tom Soilleir [10345], and also occasionally in the coarser portions of some of the smaller masses. Thus, a specimen from the mass exposed on Meall Mor, one mile south-west of Kilmelfort, shows under the microscope [8566] much idiomorphic plagioclase, biotite, a pale greenish almost colourless augite, mostly in irregular grains, some green hornblende, and interstitial alkali-felspar and quartz, which vary somewhat in proportion to the other constituents in different parts of the section.

Several of the smaller masses appear in this way to have a slightly more basic peripheral zone. This is well shown in the mass seen immediately due west of Kilmelfort and south of Loch nan Druinnean. The central portion of this mass is a medium-

grained biotite-diorite, with the usual interstitial orthoclase and quartz [10341]. As we pass towards the margin of the mass the rock gradually becomes finer-grained [10342], and finally becomes exceedingly close-grained at the actual margin [10343], showing in addition to the plagioclase a slightly higher proportion of biotite, with greenish and brown hornblende, and some pale augite, while the interstitial quartz and orthoclase are still easily recognisable.

In this connection it will be convenient to refer to what appears in the field as a passage from fine-grained diorite into porphyrite, observed in connection with some of the smaller intrusions.

A small intrusion, consisting partly of fine-grained diorite and partly of a dark porphyrite-like rock, is well exposed on the shore of Loch Melfort, about one-and-a-half miles south-west of Kilmelfort, and is seen close to the mouth of a small burn at the north-east end of Kames Bay. The dioritic portion of the intrusion is usually very fine-grained, but occasionally becomes slightly coarser. The porphyrite-like portion is only distinguishable in the field from the fine-grained diorite by the presence of porphyritic crystals of plagioclase and sometimes hornblende. The appearance in the field is somewhat suggestive of a passage between the two, as it is difficult to see any sharp line between them. Under the microscope, however, there is a sharp distinction between the porphyrite and the diorite, both in structure, composition, and the order of consolidation of the principal minerals. Moreover, the behaviour of some of the minerals in the porphyrite is exactly similar to that of the secondary minerals in certain contact-altered igneous rocks such as andesites, and the phenomena suggest that the porphyrite constitutes an earlier, though closely related, intrusion, which was subsequently succeeded and altered by the more normal type of the diorite. So that we may very probably have in these cases complex or compound intrusions, consisting of an earlier and more basic porphyrite followed by diorite.

The dioritic portion of the small intrusion of this compound nature to the south-west of Kilmelfort largely exceeds the porphyrite-like portion in amount, and in composition and structure it is precisely similar to the normal type of diorite of this area. [See 10333 and 10334.] The porphyrite-like rock shows under the microscope [10336] phenocrysts of idiomorphic zoned plagioclase, almost colourless augite, and comparatively large idiomorphic brown hornblendes, in a microcrystalline ground-mass consisting mainly of plagioclase, with probably also some alkali-felspar, and numerous small grains of pyroxene and biotite flakes. The behaviour of these latter minerals is strongly suggestive of contact alteration. They frequently occur in dense patches and aggregates as though replacing a ferromagnesian mineral such as the brown hornblende, and the larger brown hornblendes invariably show an alteration border consisting mainly of closely-packed minute biotite flakes, together with iron-ore and possibly some pyroxene granules. The outer edge of the biotite border often perfectly retains the outline of the original crystal. Another section from the same mass of porphyrite [10335] shows similar features, but

there is an absence of the porphyritic brown hornblende, and the biotite flakes are not so conspicuous in the ground-mass, though it is crowded with minute pyroxene granules. The augite phenocrysts are fresh and show good idiomorphism.

But perhaps the alteration in these porphyrite-like rocks is better seen in connection with an intrusion of diorite which forms the promontory of An Cnap, about four miles south-west of Kilmelfort. The larger part of this mass consists of the normal diorite, which occasionally shows a considerable proportion of elongated prismatic brown hornblende [10337]. Here and there the porphyrite facies occurs, usually near the margin of the mass, and shows under the microscope [10339, 10340] phenocrysts of more or less idiomorphic augite, zoned plagioclase, idiomorphic biotite, and pseudomorphs after brown hornblende. These are embedded in a ground-mass varying from microcrystalline to felsitic or crypto-crystalline, and crowded with small pyroxene granules and patches of secondary biotite flakes. Apatite of a pale milky violet colour is accessory. The original biotite is markedly idiomorphic, and so differs from that of the diorite, which is never idiomorphic, and is moulded upon the plagioclase, while in the porphyrite the biotite is of earlier consolidation than the felspar. This biotite has a corroded appearance, and is invariably surrounded by a secondary border of the small pyroxene granules. The augite phenocrysts are mostly fresh, and show very little alteration. The brown idiomorphic hornblende is now entirely replaced by granular pyroxene and minute biotite flakes, which form dense aggregates after still retaining more or less the outline of the original crystal. Patches of ill-defined aggregates of these secondary minerals are also scattered about in the ground-mass. It would certainly appear from the above that there is no true passage from the diorite into these altered porphyrites, but rather that the diorite is of slightly later date, and so may have been the cause of the alteration observed. The alteration is, on the whole, of a similar general type to that observed in a mass of porphyrite-like rock associated with the Ben Cruachan granite, and described in the Explanation of Sheet 45.

In concluding this section we may briefly summarise the principal features of the diorites of this area. They occur as numerous separate intrusions, varying considerably in size, but all closely related to one another. These may possibly represent the higher protrusions of a much larger underlying mass. The essential minerals of the normal type of diorite are plagioclase, hornblende, and biotite, together with a somewhat varying proportion of interstitial alkali-felspar and quartz. A pale augite and sometimes also prismatic brown hornblende are not uncommon in the more marginal facies. The biotite is of later formation than the plagioclase, and is moulded upon it, a feature which is very characteristic of the diorites of other areas, such as those of Ben Cruachan and Glen Fyne, and also of kentallenite, which has been shown to be genetically connected with these diorites. The Kilmelfort rocks are quartz-mica-diorites of the tonalite type, and closely resemble

some of the dioritic modifications of the Ben Cruachan granite and the quartz-diorites of the Criffel mass in the Southern Uplands. The slightly more basic marginal facies recalls the fine-grained marginal basic modifications of the Cheviot granite. There is no field evidence in the Kilmelfort area that would define within strict limitations the geological age of the diorites, but it can hardly be doubted that they belong to essentially the same period as the later granitic and dioritic masses of other parts of the South-western Highlands, such as those of Ben Cruachan, Ben Nevis, and Glen Fyne, and of the Southern Uplands.

The Kilmelfort intrusions, as comprised within the present sheet, are only very rarely sufficiently acid to be classed as granites. A part, however, of the small mass seen on the margin of the sheet, about a quarter-mile E.S.E. of Kilmelfort, on the road leading to Loch Avich, is practically a granite in composition and intermediate in structure between granite and porphyrite. Other parts of the same mass consist of diorite with brown hornblende. The granitic portion shows under the microscope [8570] phenocrysts of plagioclase and biotite in a ground-mass of smaller plagioclases, biotite, orthoclase, and quartz. The structure of the ground-mass is microgranitic, and the specimen is from the marginal portion of the intrusion. H. K.

On the south side of the hill-road above Carnassarie, and a mile and a half N.N.W. of Kilmartin, the phyllites and epidiorites are pierced by a small boss of dark biotite-diorite, which may doubtfully be referred to the same period of intrusion as the Kilmelfort diorites. J. S. G. W.

CONTACT METAMORPHISM.

All the diorite masses of the Kilmelfort area are accompanied by a contact alteration of the surrounding schists of the hornfels type. As one approaches the diorite the phyllites gradually pass into the condition of a dark micaceous hornfels, and the calcareous schists are altered into calc-silicate-hornfels. The alteration is, on the whole, of the same type as that observed along the marginal area of the Ben Cruachan granite and described in detail in the Explanation of Sheet 45, though apparently in the present area the alteration is not quite so intense. When the phyllites are interbanded with thin impure calcareous zones, a banded hornfels is produced closely resembling that of the Pass of Brander, and consisting of alternating bands of dark biotite-hornfels and calc-silicate hornfels. This type of hornfels is well seen on the south shore of Loch Melfort close to the diorite mass of An Cnap, near Asknish. The purer bands of limestone have been converted into a pale crystalline marble, and some of the impure zones now consist of pyroxene-epidote hornfels. The biotite-hornfels is well seen along the margin of the Tom Soilleir mass, and again round the margin of the smaller mass to the west of Kilmelfort. It consists of very fine-grained quartzose bands alternating with darker bands, which are seen under the microscope to be very rich in minute parallel flakes

of secondary biotite [10355]. A dark hornfels is again well exposed in connection with the small intrusion seen on the eastern margin of the map, about a quarter-mile E.S.E. of Kilmelfort, and fragments of it have been caught up and enclosed within the igneous rock. These fragments consist mainly of aggregates of small brown and greenish flakes of biotite and finely-granular felspar and quartz. The biotite flakes have often a strong tendency to a parallel arrangement [8570]. In a specimen showing the contact between a medium-grained diorite and hornfels from the same locality [8571], the hornfels is slightly different in composition, and consists mainly of granular aggregates of brown and greenish hornblende, with some biotite flakes and iron ores, in a very felspathic microcrystalline matrix. Some small patches of coarser felspar and quartz suggest an intermixture of material from the igneous rock. The line of contact between the two rocks is fairly sharp. Another specimen from the contact zone shows [8572] an intricate intermixture of granitic material and hornfels without any sharp line between the two.

The sills of epidiorite have also undergone alteration where they approach the granite. These rocks have been greatly indurated, but the essential features of the original rock have not been changed. At the promontory of An Cnap a sill of epidiorite is seen close to the diorite both on the north and south sides of the intrusion. The rock, which is a somewhat coarse variety of epidiorite, is exceedingly hard, and near the diorite loses its normal greenish colour and becomes almost black. A section of the indurated rock shows under the microscope [10352, 10353] much clear plagioclase, crowded with minute secondary inclusions, remains of elongated crystals of hornblende, chlorite, carbonates, ilmenite and leucoxene, often in elongated rods, biotite, small amphibole needles, and some interstitial quartz. Occasionally a pale yellowish epidote is present, and fairly numerous small prisms and needles of apatite [10353]. The biotite is undoubtedly a product of the contact alteration, and occurs in patches and aggregates of small ragged flakes. Apart from the presence of this mineral, however, the rock does not appear to have undergone any marked mineralogical change.

The limits of the contact alteration about the diorite masses are not easily definable. Hornfels is invariably present along the margin of each of the intrusions, whether large or small. In some cases, however, hornfels may be observed without the visible presence of any diorite and at some distance from the nearest intrusion. It is probable, therefore, that there may be considerable bodies of diorite below the surface, which, though they have affected the overlying strata, have not yet been laid bare by denudation. Further, from the mode of occurrence of the diorite masses, there is reason to believe that they may form part of one great intrusion, which has altered the overlying schists, and that the separate areas now exposed may in great part be due to unequal denudation. H. K.

DYKES AND SILLS.

Kilmelfort District.—Dykes and sills, which are evidently closely associated with the larger intrusive masses, are of common occurrence in the area here described. They are most numerous in the area to the south of Kilmelfort, which is characterised by the diorite intrusions. They are usually of small size, though occasionally in the southern portion of the area they may attain a considerable breadth. They consist of different varieties of porphyrite and felsite, and the majority of those occurring in the diorite area belong apparently to the more acid types. In the area occupied by the Lower Old Red andesites, intrusions of porphyrite are occasionally met with, but are not nearly so common as in the area further to the north-east in Sheet 45. They consist usually of the normal type of biotite-porphyrite so characteristic of the Lorne area. The normal trend of these rocks, whether they occur as dykes or sills, is in a general north-east and south-west direction. In the schistose area which fringes the southern boundary of the lava-flows, sills of biotite-porphyrite are perhaps of commoner occurrence than within the andesite area. They are pinkish or reddish rocks showing porphyritic crystals of plagioclase and a decomposed ferro-magnesian mineral, biotite or hornblende, in a felsitic base.

To the south of Loch Melfort these rocks are of common occurrence, both as sills and dykes, and cut the diorite masses as well as the older schists. Sills of a more acid type are, however, perhaps of more frequent occurrence in this area than the normal porphyrites. They differ from the typical porphyrites in their extreme poverty in ferromagnesian minerals, and some would appear to be altogether wanting in these more basic elements. Many of these rocks might perhaps be termed felsites, but they are usually so highly decomposed that it is often almost impossible to tell the character of the original rock.

Small sills belonging to these more acid types are common in the schists along the southern shore of Loch Melfort, from Kilmelfort to Asknish. They are usually only a few feet in thickness, and have been intruded along the cleavage planes of the schists. Under the microscope specimens of these rocks show idiomorphic crystals and crystalline groups of an acid plagioclase, probably oligoclase, in a ground-mass usually very turbid from alteration, but in which small plagioclase laths, and occasionally chloritic matter, with patches of granular quartz, probably secondary, may often be recognised [10347–10349]. Pyrites is common, and a white micaceous mineral probably due to the alteration of the felspar.

In the southern portion of the area similar types occur and show similar features under the microscope [8579, 8580]. Occasionally the proportion of felspar phenocrysts is considerably in excess of that of the ground-mass. Thus a specimen from half a mile S.S.W. of Carn Dearg, about three miles south-west of Kilmelfort [8581], is largely composed of relatively large idiomorphic plagio-

clases, the interstices between which are filled by fine-grained plagioclase, orthoclase and quartz playing the *rôle* of ground-mass. H. K.

Craignish.—The two types of dykes and sills just described are continued, together with a few lamprophyre intrusions, across the high ground south of Loch Melfort, where they attain their maximum development, into the promontory of Craignish.

In addition to following the planes of schistosity in the schists, these dykes and sills have also been occasionally intruded along lines of shear and thrust in the quartzite, while in the islands of Scarba and Lunga they are in some cases injected for a considerable distance along the earlier dykes of epidiorite. B. N. P.

The numerous dykes with a N.N.E. trend which appear along the southern margin of the plutonic masses of Tom Soilleir become fewer in number and generally smaller in size as they are traced down the peninsula of Craignish. They are intruded along the cleavage-planes of the phyllites, and consequently have a considerable hade to the E.S.E. The schists on the hanging wall have often been denuded away, so that a considerable expanse of the flank of a dyke is laid bare. Hence the outcrops form distinct ridges much broader than the mere thicknesses of the dykes, which commonly range from five to twenty feet. Most of the dykes are considerably shattered at the outcrop by a closely-set system of cross-joints, but at a depth of a few feet the rock occurs in larger blocks and is very tough to work. The large dyke at the north-west corner ot Loch na Bèiste, and the more easterly of the two porphyrite dykes one-third of a mile east of Mullach Dubh, are at these localities full of inclusions of phyllites. As these "igneous-breccias" appear just before the dykes disappear from view, it is thought probable that the "igneous-breccias" mark the roofs of the dykes, though the phyllites are not actually seen to arch over them.

The majority of the dykes are pinkish porphyrites, with phenocrysts of plagioclase, biotite, and either hornblende or augite quite decomposed. Some of the dykes, however, have no visible melanocratic constituent. Examples of the latter kind are found 200 yards west of the Burial Vault above Barbreck House; in the burn 300 yards below Hill Park; on the roadside north of Barrananaoil; and at the south end of Eilean Mhic Chrion (Loch Craignish).

Neither felsite nor lamprophyre dykes are common. They are smaller than the average porphyrite dyke, and their outcrops cannot be traced more than a few hundred yards. The following localities for the better exposures of each class may be cited. Pale-coloured dykes of felsite were noticed one-third of a mile north-west of Barbreck House, and in the burn above Sluggan to the east of the Barbreck River.

A minette dyke was found one-third of a mile west of Barravullin, another occurs between two porphyrite dykes one-third of a mile east of Mullach Dubh, whilst the N.N.E. dyke south of Soroba Hill is also a mica-lamprophyre.

Kilmartin.—Whilst the N.N.E. dykes are so numerous in Craignish, where the lavas and plutonic masses of Lower Old Red Sandstone age occur in their line of trend, on the east side of Loch Craignish dykes of the same period are relatively infrequent.

A porphyrite dyke is intruded along the planes of strain-slip cleavage of the black schist in the hollow west of Dun an Dubh Challa, and hades at so large an angle to the east that it might be better called a sill. The small mass of hornblende porphyrite on the eastern flank of Corlach is probably a portion of the dyke isolated by denudation. The southward continuation of the same rock is probably represented by the sill intruded between the limestone and pebbly quartzite on the hill east of Lochan Druim an Rathaid.

It should be noted that the Lower Old Red Sandstone dykes are thrown by the transverse faults of the district, which are therefore much younger than the movements which gave rise to the folding and schistosity. H. B. M.

Intrusions of porphyrite are still rarer in the area east of the Kilmartin Burn, being restricted to a few dykes trending with a N.N.E. trend and conforming to the general strike of the schists, between Kilmartin and the Pass of Creagantairbh.

A lamprophyre dyke has pierced a large mass of epidiorite near Kames. It is a fine-grained dark rock containing plates of biotite, and weathers with a brown crust. Under the microscope [6692] the section shows plates of pale brown biotite, more or less altered plagioclase, abundant carbonates and magnetite. The rock is therefore a kersantite. J. B. H.

Area South of Crinan Canal.—A few dykes of this date of intrusion occur in this district. A porphyrite dyke with pink felspar and decomposing ferro-magnesian mineral, evidently hornblende, is quarried for road metal at the roadside, a little to the east of Belanach Bridge, and can be traced from that point along the strike of the schists south to the edge of the map. Another dyke of similar porphyrite and also one of lamprophyre can be followed in the same direction from near the forkings of the road to Crinan pier almost to the head of Kyle Scotnish. B. N. P.

PETROLOGICAL NOTES ON THE LOWER OLD RED SANDSTONE DYKES IN CRAIGNISH, KILMARTIN, AND THE ISLANDS.

A limited number of these rocks have been sliced for microscopic examination. The majority of them are greatly decomposed, but can be divided into felsites, porphyrites, and lamprophyres. There can be no doubt that the whole series was emitted from the same parent magma, as transition stages between the different groups are occasionally met with.

Felsites seem to be rare, as is the case in many parts of the Southern Highlands. The best example which has been sliced is one mapped by Mr. Muff, one-third of a mile north-west of Barbreck House, Craignish. It is a pale yellow or creamy rock without porphyritic crystals, but consisting of a fine-grained micro-

poikilitic aggregate of quartz and felspar showing micrographic structure occasionally. Small crystals of magnetite and zircon are also visible in the slide, and minute irregular areas of quartz, which are presumably secondary.

By far the greatest number of the dykes of this series are porphyrites which carry phenocrysts of plagioclase felspar. Some of them contain a considerable amount of quartz, but only in the ground-mass, as this mineral does not appear among the products of early crystallisation. In these *quartz-porphyrites* there is often little of the ferro-magnesian silicates, and the rocks are consequently pale-coloured and weather to grey or pale yellow. An example of this group occurs on the road a quarter of a mile north-east of Barrananaoil (Craignish). It contains idiomorphic porphyritic crystals of oligoclase in a matrix of felspar (orthoclase and oligoclase), quartz, and iron oxides. In other rocks of this group the felspars are in large measure altered to sericite, while calcite also is very abundant. This type is very common along the shore south of Kilmelfort, and has been described from that locality by Mr. Kynaston (see p. 73).

A more normal type of *porphyrite* is commoner, and contains crystals of dark ferro-magnesian minerals visible in the hand specimen, along with porphyritic felspar in a ground-mass consisting mainly of felspar, but often with more or less interstitial quartz. Hornblende and brown biotite are the principal ferromagnesian minerals in the more acid varieties, but augite may be present in those which contain no primary quartz. The porphyritic felspars in the former case are mostly oligoclase, but in the more basic varieties it is often andesine or labradorite, and is generally zonal. The phenocrysts are usually bounded by sharp crystalline faces, but in many of the rocks their slightly rounded forms indicate a certain amount of corrosion. The augite gives characteristic octagonal cross-sections, and has a pale green colour; it is rarely seen in a fresh state. The hornblende appears to have been mostly pale brown, but is almost as universally decomposed as the augite. The brown biotite forms idiomorphic six-sided plates, but may have its borders blackened by corrosion. It is more frequently in good preservation than any other ferromagnesian mineral, and is the only one of them which reappears in the ground-mass as an element of the second crystallization. In one rock from half a mile W.S.W. of Acharonach, Craignish, there is a good deal of this later biotite in a matrix consisting of idiomorphic felspar and interstitial quartz; this gives the rock a resemblance to the lamprophyres, but the presence of porphyritic felspars makes it more convenient to group it with the porphyrites. It forms a transition, however, to the typical minettes which occur in this area.

The ground-mass of these rocks is, as a rule, microcrystalline, and consists of small idiomorphic felspars, often fluidally arranged. Many of the specimens seem to be quite free from primary quartz; when this mineral does occur it is interstitial, and forms the last product of crystallization. Micropegmatite has not been observed

in the ground-mass of these porphyrites. A very fine-grained microlithic matrix resembling that of the pilotaxitic andesites can be seen in a few of the dykes of this series, and occasionally the rocks of this type have their porphyritic felspars honeycombed with enclosures of the matrix; this gives them a very close resemblance to many of the volcanic andesites which belong to the same epoch of igneous activity. Rocks of this type occur on the roadside south of Lergychoniemore, Craignish, and half a mile north-east of Kilmartin.

The *lamprophyres*, being prone to decomposition, are rarely so fresh as the porphyrites. On the mainland they seem to be comparatively scarce; the best examples are two which occur in Craignish, a third of a mile east of Mullach Dubh, and a third of a mile W.S.W. of Barravullin. Both are dark, moderately fine-grained rocks, with many glancing scales of dark brown mica. Under the microscope they prove to be full of biotite, intensely pleochroic, in tints ranging from very pale yellow to dark brown. They have hexagonal boundaries, often with zig-zag edges, and are paler in their centres than along their borders. Many are entirely fresh and contain few endomorphs; some are bent, evidently by fluxion movements in the rock. There is no porphyritic felspar, but pseudomorphs of calcite after idiomorphic augite are numerous; on the surfaces of these little scales of biotite are laid tangentially. Between crossed nicols the larger plates of mica may show polysynthetic twinning. The matrix consists of weathered felspar with calcite, chlorite, and other secondary products. The felspar is in small prisms, so much altered that the species cannot be identified; but it is probable that these rocks are minettes, and have had a ground-mass of the panidiomorphic type. Apparently there has been no primary quartz. Apatite and magnetite are common, the latter sometimes aggregated in the biotite; calcite is scattered throughout the slides, and fills small microlitic cavities along with secondary quartz.

In Jura also dykes of porphyrite and lamprophyre occur, closely resembling those of the mainland, but, to judge from the specimens which have been collected, they are mostly in an advanced stage of decomposition. In appearance there is not much difference between the two classes of rocks; both are rather fine-grained, and weather with pale brown and buff colours. The porphyrites, however, contain decomposed phenocrysts of felspar, while these are absent from the lamprophyres. Probably both vogesites and minettes are present, but can no longer be distinguished from one another.

Lamprophyres, very similar to those of Jura, have been mapped by Dr. Peach in the island of Scarba, but porphyrites seem to be very rare, as, among a considerable number of slices prepared from the dykes of that island, no porphyrites were found. These lamprophyres are rather fine-grained, and in their decomposed state have grey and brown colours of various shades. They are often spotted with calcite, and show no conspicuous phenocrysts to the naked eye, though small dark pseudomorphs after the ferromagnesian minerals are often visible with the aid of the lens.

Some of them contain dark brown hornblende in small elongated idiomorphic prisms; in others yellow biotite is the dominant ferromagnesian mineral. Many show pseudomorphs of calcite and chlorite having the outlines of pyroxene. There is no porphyritic felspar in the specimens examined. It is probable that minettes, vogesites, and kersantites are all present in the island, but they are so decomposed and filled with carbonates and other secondary products that there is little to be said about them. The best preserved of these dykes is one from the bay east of Uamh nan Cabhar, on the south coast of the island, about half a mile west of Rudha Righinn. It is a dark minette with much fresh biotite and pseudomorphs after porphyritic augite, and closely resembles the dykes of the same kind above described as occurring in Craignish. J. S. F.

CHAPTER VIII.

Rocks of Tertiary Age.

I. TERTIARY IGNEOUS ROCKS OF MULL.

The small portion of the Isle of Mull which appears on the northern edge of the map is also shown in its natural connection on the margin of the adjoining sheet (44). Since it is only formally included in the sheet now under description, its geological relationship being with the rest of the island to which it belongs, a brief notice will be sufficient in this place.

This part of the south coast of Mull presents a bold range of cliffs some 900 feet in height, of which only the summit and the base are accessible. At one place in the lower part of the cliffs are some natural arches, which have attracted attention from an early time.* Geologically this strip bears no relation to Jura and Scarba. It is the southerly termination of the "basalt-plateau" country which makes up the greater part of the Isle of Mull, and consists essentially of igneous rocks of Eocene age.

The cliffs present to the eye a stratiform appearance, and the section which they exhibit is, in fact, made up by a pile of numerous generally parallel sheets. These are of two different rocks, both of basic composition. Firstly, there are *basaltic lavas*, in a thick succession of flows, overlapping and superposed, doubtless representing, as Sir Archibald Geikie has urged, eruptions of the fissure type. These basalts are for the most part conspicuously amygdaloidal. They are rocks of close texture, and have suffered considerably from secondary changes. Secondly, there are sheets of olivine-dolerite which are of more evidently crystalline texture than the lavas, and are in better preservation. They make strong features, and have a more or less marked vertical columnar jointing. These dolerite sheets are *intrusive sills*, penetrating usually along the surfaces of junction of the lava-flows, and so preserving a general parallelism, but sometimes cutting obliquely across. Irregularities affording clear evidence of intrusive relations may be seen at Carsaig Arches and Malcolm's Point.

The whole section, with exceptions to be noted, is made up by alternations of these two rocks. In the lower part the dolerite sills play only a subordinate part; but they come in in greater force higher up, make the strong escarpment at the top, and present broad outcrops on the more level ground behind. The thickness of about 1000 feet here exhibited represents only a part (perhaps a third) of the whole, and it is clear that prior to the great erosion which

* See Earl Compton, *Trans. Geol. Soc.*, vol. v., pp. 369-374, pl. 19-21; 1821.

has affected this region in later Tertiary times the lavas and sills must have had a much greater extension southward than appears on the map of to-day. The part that is seen in these cliffs is the lowest part of the succession. The whole has, at this place, a gentle inclination to the north-west, so that the several members rise slowly as we follow the coast eastward. Just beyond the limits of this map the base is reached, and the Mesozoic strata emerge beneath, making a considerable show in Carsaig Bay.*

The section which falls within the present sheet possesses a certain special interest, in that it includes one of the *bedded fragmental deposits* which are occasionally intercalated in the basalt succession, giving evidence of fluviatile conditions and of terrestrial vegetation during the volcanic period. This particular occurrence has been described by Mr. Starkie Gardner.† The stratified deposits rise from sea-level at Carsaig Arches, and may be followed continuously in the lower part of the cliff to Malcolm's Point and some half a mile beyond. Their position is thus very near the base of the basalt succession. Near the Arches they are only a few feet thick, consisting of bedded basaltic tuff with sandy material. This deposit rests on basaltic lava, and is covered by a dolerite sill. Followed past Malcolm's Point, the bedded group thickens, and there is more non-volcanic material mingled with the basaltic *débris*. At about 500 yards beyond the Point the thickness is some 12 feet, and there are isolated rolled pebbles of flint, which become more numerous, until the deposit may be described as a conglomerate. The last good section, near the limit of the map, shows 15 feet of conglomerate, composed of rolled flint pebbles up to 4 or 6 inches in diameter, and passing up into a bedded basaltic tuff, surmounted by the same dolerite sill. Below the conglomerate is about 30 feet of amygdaloidal basalt. A. H.

II. TERTIARY DYKES.

Kilmelfort District.—Dykes of dolerite and basalt of Tertiary age are exceedingly numerous throughout the entire area. They vary considerably in breadth, and may often be traced for considerable distances across country. Their general trend is in a north-west and south-east direction. The dykes often preserve a very straight course for a long distance, but may be diverted along older lines of faulting, or may often have a sinuous, twisting course.

Compound dykes, consisting of several distinct intrusions, are by no means uncommon, although the different members do not show any very wide range of composition. Occasionally several neighbouring but separate dykes may coalesce to form one of these compound dykes.

At Easdale one of the striking sections on the coast is furnished by a multiple dyke which cuts the black slates about a furlong south-east of the School-house. This intrusion is made up of at

* See Judd, *Quart. Journ. Geol. Soc.*, vol. xxxiv., p. 660-741; 1878.

† *Quart. Journ. Geol. Soc.*, vol, xliii., pp. 281-283; 1887.

least ten bands of dolerite, which, though in a general sense parallel to each other, occasionally diminish in thickness, bend in their course, and thus allow wedges of the surrounding slates to come in between them. Where no such foreign intrusions appear, the whole igneous mass might at first be taken for a single broad dyke, but a little examination shows that its individual bands are in several cases separated from each other by a selvage of black glass, which is sometimes two inches thick, but dwindles down to a mere film or glaze on the wall of the dyke. The dolerite assumes an exceedingly coarse grain for several inches before it is succeeded by the vitreous layer. Here and there strips of glass lie within the body of the dyke some way back from the wall, without any evidence that they mark outer margins of distinct dykes. One of the dykes presents a number of cavities, some of them 3 or 4 inches in diameter, which are lined with small pea-like spherules of the same black glass. Many of the dykes have a spherulitic structure at their outer margins, the spherules being occasionally grouped in rows.

The Tertiary dykes are again well exposed along the shores of Loch Melfort, and often include examples of composite dykes. Two of these may be seen where a stream enters the sea at Kames Bay on the east shore. A couple of olivine-basalt dykes are there split up longitudinally by basalt dykes of a less basic nature, the edges of the latter being chilled against the earlier rock, and showing a margin of black basalt-glass. Another similar illustration occurs at Kilmelfort Pier, on the north side of the loch. Close to Kilmelfort the basaltic dykes are especially numerous, and stand out in vertical walls above the schists and diorite which they traverse. Branching dykes are often seen, and occasionally a dyke may be observed to send off small sills into the surrounding schists.

The usual type of dyke is a fine-grained olivine-dolerite, though they vary from basic olivine-dolerites and basalts to augite-andesites. The less acid types are occasionally seen to cut obliquely across the more basic. Some of the dolerites show a relatively high proportion of felspar, and some of the crystals may be of comparatively large size, thus giving the rock a somewhat porphyritic appearance. Both the doleritic and basaltic types are often vesicular.

A specimen of dolerite, somewhat rich in felspar, from three-quarters of a mile south-west of Kilmelfort, shows under the microscope [10283] much idiomorphic plagioclase in larger and smaller individuals, which frequently shows pericline twinning, fresh olivine, grains and ophitic plates of pale brownish augite, and magnetite.

Varieties allied to andesite have been noticed in the neighbourhood of Easdale, and on the south side of Loch Melfort, near Asknish, and in other places. A specimen from a point a quarter of a mile north of Easdale shows phenocrysts of clear idiomorphic plagioclase in a ground-mass consisting mainly of small plagioclase laths and grains of augite and magnetite. There is no olivine. [10284.]

Craignish and the Northern Part of the Kilmartin District.—Barr Mòr, a conspicuous flat-topped hill situated on the west side of Craignish, near the farm of Barrachan, is capped by a sill of highly decomposed dolerite which appears to have been fed by a more or less vertical dyke, for such a dyke can be traced down the north face of the hill till it disappears under the deposits of the raised beaches. A similar dyke on the further side of the beach deposits is in line with it, and can be traced to the present coast.

B. N. P.

The north-westerly dykes, which are so extraordinarily abundant in Degnish and Asknish, are continued across the north of Craignish and the country north of Kilmartin. Here it is no uncommon thing to meet with 30 to 40 basalt dykes to the mile, but it has been found possible to represent only about one-third of this number on the map. This belt of closely-spaced dykes is continued in a south-easterly direction across Loch Fyne and through Cowal* to the neighbourhood of Dunoon, a total distance of 40 miles.

The coarser-grained dykes are olivine-dolerites, generally ophitic and non-porphyritic. They are as a rule broader (about 8 to 30 feet) than the fine-grained dykes, which are usually between 2 and 12 feet wide. The former generally possess a horizontal columnar jointing, to which is added towards the fine-grained edges a vertical jointing parallel to the cheeks of the dyke. In the dykes of the latter class the jointing most commonly found is that which forms horizontal and rudely hexagonal prisms, and the joints become more closely spaced towards the edges of the dyke. This jointing is replaced in some cases by a platy jointing parallel to the length of the dyke, and best developed near the margin.

The dykes are not abundantly vesicular. The vesicles of the finer-grained dykes are small and commonly occur a few inches from the walls of the dykes, but the olivine-dolerites often have a number of large vesicles disposed along a narrow belt down the centre of the dyke.

The olivine-dolerites disintegrate more readily than the basalts, probably largely on account of the decomposition of the olivine permitting the loosening of the other crystals by frost, etc. Consequently their courses are almost invariably marked by a hollow. On the other hand, a fine-grained basalt varies in its elevation relatively to the country-rock. Where intruded through phyllites or limestones it often forms a ridge, but in epidiorites or quartzites its surface is generally sunk below the level of the country-rock.

Multiple dykes formed by two or more intrusions running side by side in the same fissure are occasionally met with. A good example is the one which runs across Craignish from the north end of Eilean Mhic-Chrion to the pier at Lunga House. At the

**Memoirs of Geol. Surv.*—"Geology of Cowal" (1897), p. 152, and "Geology of Mid-Argyll" (1905), p. 117.

latter place it is formed of at least ten dykes differing in composition and exhibiting the usual fine-grained margins.

Another multiple dyke, exposed on the shore a little over half a mile south-west of Kintraw, shows in order from the north-east :—

	Feet.
Basalt, with chilled edges, dying out	1
Dolerite, weathering brown, and with chilled edge on north-east side	6
Basalt, with rude columnar jointing, apparently chilled against preceding dyke	25
Short gap.	
Glassy hypersthene andesite (see p. 89, and plate viii., fig. 1), apparently veined by succeeding dyke	2
Vitreous basalt, with chilled edges on both sides	1½
Basalt, with small phenocrysts of felspar, rude cross-jointing in columns, chilled on both margins	20

One or two dykes, which should perhaps be considered as varieties of the composite type, whilst exhibiting the usual fine-grained or vitreous margin, possess also a central glassy band. The central portion is not sharply marked off from the lateral members, but nevertheless sends veins into them. The veins sometimes anastomose and thus produce a brecciform structure. These dykes, as suggested by Mr. Harker, are probably formed by "the splitting and evisceration of a partially consolidated dyke by a slightly later injection of a magma sufficiently different to be distinguishable."*

One of these dykes cuts the edge of the sheet at latitude 56° 11′ 27″ and, running in a north-westerly direction, crosses the Barbreck River half a mile above Barbreck House. It passes just to the north of Barrananaoil, and continues towards the north-west on the far side of the big peat-moss. The central glassy portion expands and contracts in breadth and sometimes dies away, so that it appears at the surface as a series of elongated lenticles.

The large dyke which forms such a striking feature on the raised-beach platform at Craigdhu (Craignish) has a central vitreous member containing small phenocrysts of plagioclase, hypersthene, and augite. This band is 25 feet broad and is bounded on both sides by belts of dark bluish finely-crystalline basalt, jointed in hexagonal columns, which lie perpendicular to the walls of the dyke. The band on the south-west side is about 15 feet thick, whilst that on the north-east measures 30 feet.

The dyke which trends almost due east and west past the northern end of the outcrop of pebbly grit on Dun an Dubh Challa is a porphyritic olivine-dolerite containing analcime.

Several of the basalt dykes are intruded along lines of fault, but are themselves not crushed. Since the porphyrite dykes of Lower Old Red Sandstone age are thrown by the faults, the latter must date from the period intervening between the intrusion of the two sets of dykes. H. B. M.

* Tertiary Igneous Rocks of Skye (*Geological Survey Memoir*) 1904, p. 298.

Area West of Kilmartin Burn.—The Tertiary dykes in this area consist of several varieties of basalt and dolerite, and have a general north-west and south-east trend. Although numerous, the larger number are small and cannot be followed for any distance. Two compound dykes have been traced eastward from near the head of Loch Craignish, the one passing by Loch Fearphorm and the other through Strone. They are supposed to be the continuation of the two compound dykes which cross the Craignish peninsula.

On the coast section some interesting examples of the behaviour of these dykes can be observed. In one instance a dyke suddenly turns at right angles to its course, and then in a short distance resumes its former direction. In another a dyke passes from a band of epidiorite into the phyllites, becomes much thicker, and is intruded for some distance along the line of junction between the two rocks, afterwards resuming its former trend.

In a third case, a north-west and south-east dyke crosses an east and west dyke of coarse dolerite, and at the point of intersection the former is reduced to one-fourth of its breadth and shows chilled edges. This fact proves that these dykes are not all of the same period of intrusion. J. S. G. W.

Area East of Kilmartin Burn.—This district is traversed by a plexus of Tertiary dykes striking approximately N.N.W. These intrusions vary in composition from basic olivine-dolerites to plagioclase-augite-rocks of intermediate type, which occasionally assume the character of augite-andesites. The rocks are frequently porphyritic, idiomorphic felspars standing out conspicuously in a finer matrix. A typical example from a dyke near Baroile contains numerous phenocrysts of felspar in a dark matrix. Under the microscope [6690] the rock is seen to be made up of crystals and crystalline groups of basic plagioclase in a matrix of ophitic olivine-dolerite. These dykes vary in texture from fine-grained rocks to others in which the structure is coarse and approaches that of a gabbro. J. B. H.

Jura.—Tertiary olivine-basalt dykes of the ordinary type are numerous in the northern part of the island of Jura, where they have as a rule the normal north-west and south-east trend. Two instances of a departure from this rule occur at the north end of the island. The first of these appears on the east coast at Con Tom, north of Barnhill House, and runs west and W.N.W. to the opposite coast. The other east and west dyke forms a striking feature in the cliffs at the extreme northern end of the island, rising vertically through the quartzite and the earlier epidiorite intrusions.* S. B. W.

PETROLOGICAL NOTES ON THE TERTIARY DYKE ROCKS.

The prevalent type belongs to the ophitic olivine dolerites; some of them contain analcite, and may be described as teschenites. There are also quartz-dolerites and rocks of the tholeiite class, some

* These two examples may be of late Carboniferous age.—B. N. P.

of which contain pseudomorphs after olivine. Variolites, andesites, and camptonites also occur, and near Easdale there is a curious intrusion which seems to consist of a rock allied to mugearite.

The ophitic olivine dolerites consist essentially of plagioclase, augite, olivine, and iron ores. There are both coarse-grained and fine-grained rocks of this group, and, especially in the former, the ophitic structure is often very perfect. The olivine occurs in small greenish grains, mostly in large measure fresh, but showing incipient decomposition into serpentine. The augite is almost everywhere reddish brown and very feebly dichroic even in thick sections. It is not idiomorphic, and occurs only in the ground-mass of the porphyritic rocks. The felspar is all plagioclase of basic sorts; as it is always fresh it can be accurately determined by modern petrographic methods. A large number of crystals showing both albite and Carlsbad twinning were examined by Michel Lévy's method,* using the new diagrams of Rosenbusch.† Most of them proved to be bytownite (Ab 25, An 75). Others were slightly more basic, containing about 20 per cent. of the albite molecule. This was confirmed by observations on the refractive index (Schroeder van der Kolk's method),‡ and on the specific gravity and extinctions of cleavage flakes. Fragments from porphyritic felspars which attain a length of an inch or more in a dolerite dyke on the beach south of Asknish contained rather more soda felspar (Ab 40, An 60), but were not absolutely homogeneous. Many of the larger crystals are zonal, though this is not pronounced; the outer portions are slightly more acid and have lower extinctions than the centres in sections perpendicular to the albite twin-plane. In the porphyritic rocks the felspars of the ground-mass are basic labradorite and bytownite (Ab 30, An 70), but many of the small laths embedded in the augite are as basic as the majority of the phenocrysts.

The occurrence of porphyritic plagioclase felspar in these dolerites is rather common, and the crystals may be of considerable size, as in the instance above cited. They are mostly of tabular shape, but their faces are frequently rounded by corrosion. They show elaborate twinning, and may contain enclosures of black magnetite or dark-coloured glass, sometimes arranged in zones. Porphyritic olivine is conspicuous only in the rocks with a fine-grained matrix. Phenocrysts of augite were not seen, and must be rare. The ground-mass in all cases is ophitic; it may be coarse or fine. In the latter case the structure becomes micro-ophitic or perhaps sub-ophitic, but even in these rocks traces of glass are rarely met with. The iron oxides are principally ilmenite, which forms grains, plates, and networks, but large skeleton crystals do not occur.

Teschenites.—In a few of the ophitic olivine dolerites there are

* A. Michel Lévy—Etudes sur les Feldspaths (1894).

† H. Rosenbusch—Mikroskopische Physiographie, vol. i. (1905).

‡ J. L. C. Schroeder van der Kolk—Mikroskopische Bestimmung der Mineralien (1906).

nests of radiate zeolites which gave grey polarisation colours, but were not completely determined mineralogically. With them analcite occurs in perfectly transparent interstitial patches, possessing no crystalline outlines, and associated sometimes with calcite and chlorite. There can be little doubt that it is secondary after felspar, or at any rate a very late pneumatolytic deposit in miarolitic spaces. Occasionally replacement of felspar by patches of isotropic analcite can be seen in progress, a fact which clearly establishes the secondary nature of the mineral, in this case at any rate. These rocks have very close affinities with the *teschenites*, with which, indeed, they may quite well be placed. In general appearance they differ very little from the commoner olivine dolerites. They contain olivine, and their augite encloses the felspar in ophitic manner. Some of them contain phenocrysts of labradorite half an inch in length. The pyroxene, however, has more of a purple shade than in the other rocks, and is sometimes grey or faintly green, and has marked dichroism with frequent hour-glass and zonal structures. Often they contain a good deal of apatite in fine needles, and a little deep brown, strongly pleochroic biotite. This last is a very early mineral, and usually borders the iron ores and the olivine. Hornblende was not observed in any of the rocks of this group. The best examples come from Scarba (one-third of a mile east of the south-west corner of the island) and from a locality on the mainland 500 yards W.N.W. of the top of Barr Ban (about one mile south of Crinan Harbour). Mr. Harker* has described Tertiary teschenites from Arran.

Dolerites without Olivine, Quartz Dolerites, Tholeiites, etc.—A dyke of quartz dolerite occurs at Garb Leathad, Glen Lussa, Jura. It is very distinct in many characters from the Tertiary olivine dolerites which prevail over this area. Rocks of this class are also abundant as sheets and dykes in the Midlothian district, and are there regarded as of late Carboniferous age. The rock from Glen Lussa contains no olivine; the augite is pale brown, sometimes slightly green, but not reddish like that of the olivine dolerites. There are small phenocrysts of labradorite (Ab 40/An 60 by extinctions in the symmetrical zone and by refractive index), with external zones of more acid composition and smaller extinction angles. A few small porphyritic augites occur also as elongated narrow prisms. They are brownish green, simply twinned, and resemble the so-called "sahlite" of the quartz diabases. The gound-mass consists of augite and plagioclase, the augite being later in crystallization than the felspar, and far less perfectly idiomorphic. The felspar yields lath-shaped sections; the augite forms irregular granules, but there is no good ophitic structure. A small amount of mesostasis occurs, with acicular or reticulate felspars, a turbid, decomposed substance (perhaps an altered glass), and irregular areas of quartz which probably are not entirely secondary.

Similar quartz dolerites occur on the south side of Loch Melfort,

* The Geology of North Arran (*Memoirs of Geological Survey*), p. 112.

near Rudha na Tighe Loisgte. At this locality there is a group of dykes all presenting certain features in common; if they belong to the same set of injections they show that there are transitions between the ophitic olivine dolerites and the group of rocks which we are now considering. Of six dykes examined microscopically, the one which occurs farthest to the south is richest in olivine, and has a rather well-marked ophitic structure. The sixth of these dykes in order northwards contains a little olivine, but is not ophitic, and has small patches of partly crystallised interstitial ground-mass. Its augite is of a very pale greenish-brown colour. Three other dykes are free from olivine, non-ophitic, and more or less rich in intersertal, finely crystalline, or devitrified ground-mass between the larger felspars and augites. Where this mesostasis is well crystallised it often contains a small amount of quartz. These rocks are typical tholeiites. The study of this group of dykes leads to the conclusion that when olivine is abundant the augite is darker in colour and the rock tends to have ophitic structure; when olivine is scanty the augite has paler tints and the structure is intersertal, with a varying amount of glassy or finely crystalline material in which quartz may appear as the last product of crystallisation.

In the second of these dykes at Rudha an Tighe Loisgte there is, in addition to the granular greenish-brown augite and lath-shaped sections of felspar, a considerable amount of vitreous base. This glass is darkened and rendered semi-opaque by abundant skeleton growths of magnetite; there are also small needles and microliths of felspar and granules of augite. This rock seems to present close affinities with the well-known Watt Carrick dyke of Eskdalemuir which has been described by Sir Archibald Geikie* and figured by Dr. Teall.† It also resembles in microscopic character the rocks which have been grouped under augite porphyrite and described as "weisselbergite" by Continental petrographers.

A very similar dyke is one of a group which occurs at Sloc an't Siomain, near Easdale (Plate VIII., fig. 2). It contains no olivine, but is rich in dark-brown glass which is filled with growth forms of magnetite. Plagioclase felspar is the principal mineral constituent, and occurs in few small idiomorphic phenocrysts and numerous elongated laths or rods, which are nearly square in cross section and have often dark glassy cores. Forked crystals, H shapes, feathery and skeleton growths, are also common. By Becker's method ‡ these felspars proved to be labradorite (Ab 40/An. 60), and this was confirmed by observations on refractive index (Schroeder van der Kolk's method) and extinctions in the symmetrical zone of albite twins. There is a tendency for these crystals to form divergent or stellate groups, and the slides in

* Proc. Roy. Physical Soc. Edin., vol. xi. (1880).

† British Petrography, pl. xxiv., fig. 1.

‡ Annual Report of the U.S.A. Geological Survey, vol. xviii., pl. 3 (1898), p. 34.

some parts present resemblances to variolites. The augite occurs in small, pale-yellow grains which lie between the felspars embedded in the brown glass, and as compared with the felspars they are very free from glass enclosures. Their colour is so pale that they are hardly distinguishable from the felspar in ordinary light. Twinning is rare or absent in these small pyroxenes. Some of the crystals have the usual eight-sided transverse sections, but most of them are imperfectly formed. One or two larger porphyritic augites of yellow or pale brown colour are also present in the section. The abundant glassy base contains, in addition to magnetite, rods, skeletons, and reticulate growths of felspar. In places the glass is dark-brown and turbid, but there are clearer and paler areas. This may be due to a separation of the glass from the crystalline ingredients of the rock, such as has been described in many of these Tertiary dykes. Minute rounded spots filled with a transparent colourless mineral which appears to be quartz are common in many parts of the slide. These are steam cavities like those occupied by hyalite which have been described by Professor Judd in the Tertiary dykes of Arran. Around them the glass is greenish and decomposed; a thin layer of isotropic opal forms the boundary of the cavity.

Some excellent examples of these tholeiites or olivine-free dolerites with vitreous intersertal material occur about half a mile N.N.E. of Salachary (three and a half miles north of Kilmartin). Four specimens from a composite dyke which occurs there were selected for slicing. The most crystalline of these rocks contains small zonal felspar phenocrysts and greenish-brown augite, with a considerable amount of somewhat decomposed glassy base. In this rock there are rounded steam cavities partly occupied by glassy substance which has leached in from the surrounding mass and contains the same skeleton felspars and augites as are visible in the glass elsewhere. This phenomenon has been described in dykes of this group by Dr. Teall,* Professor Judd,† and Mr. Harker.‡

Another specimen from these dykes very closely resembles the highly vitreous tholeiites from Easdale and Loch Melfort above described, except that the augite has been replaced completely by pseudomorphs of dark green and highly pleochroic biotite, which show perfectly the outlines of the original pyroxene. The furthest south of the four dykes is the most vitreous of all, having quite the appearance of a dark pitchstone in the hand specimen. Its abundant brown glass is spotted with paler areas and is crowded with skeleton growths of augite, which tend to form rectangular networks. Small phenocrysts of felspar and of enstatite occur in this rock. If this be, as there seems reason to believe, a glassy facies of the tholeiites, the rhombic pyroxene is an interesting feature. It shows the andesitic affinities of these rocks. Enstatite

* Geol. Mag. (1889), pp. 481-483.

† Quart. Journ. Geol. Soc., vol. xlvi., p. 378 (1890).

‡ "Tertiary Igneous Rocks of Skye," p. 400 (1904).

occurs also in the vitreous portion of a tholeiite dyke, 900 yards north by east of Salachary.

Variolites are known to occur in two localities in this sheet, and probably if carefully searched for would prove to be more abundant than has been suspected. The best example which has been collected is one from the north side of the stream which enters the north-east side of Kames Bay, Loch Melfort. According to notes furnished by Mr. D. Tait, it is a one-foot east and west dyke with glassy selvages, running alongside of a six-foot dyke, cutting the diorite of this locality at its northern margin. Microscopic slides of this rock show that the variolitic structure is exceedingly perfect. Long straight rods of felspar diverge from centres, branching as they pass outwards. Plumose growths of greenish augite occur among the felspar, and there are iron oxides in grains and rods which build up imperfect networks. Small elongated phenocrysts of felspar, with large glass enclosures, occur sparingly, and there are minute rounded steam cavities filled with chlorite. This dyke is almost identical with those which have been described from Ardmucknish by Mr. E. B. Bailey.† At the margin it becomes very dark and glassy, passing into a spherulitic tachylite like those which have been described by Professors Judd and Cole,‡ and Mr. Harker.§

A variolitic rock of a different kind occurs at Sloc an't Siamain, near Easdale, as one of a group of dykes. This rock weathers with a nodular surface covered with rounded projections about a quarter of an inch in diameter. It contains a few small vesicles occupied by calcite, chlorite, and quartz. The whole rock is fine-grained, without phenocrysts, and in section proves between crossed nicols to consist mainly of radiate brushes of felspar. There are also many skeleton growths of magnetite, which sometimes have a divergent arrangement. In ordinary light the slide looks almost structureless except for these reticulate iron ores. Specks of chlorite in the felspathic matrix perhaps represent original augite. This dyke contains no olivine, and corresponds closely to some of the less basic tachylytes which have been described from Skye by Mr. Harker.‖

An *andesitic pitchstone* occurs at the head of Loch Craignish, a little over half a mile south-west of Kintraw, forming a central band in a Tertiary dyke (see p. 83 and Plate VIII., Fig. 1). In the hand specimen the rock is a dark-green resinous glass with conchoidal fracture, and shows a few small phenocrysts, mainly of felspar. In the slide a brownish glass greatly preponderates; it is rendered cloudy by dense swarms of globulites, margarites, and trichites, with clearer and paler areas surrounding the crystals of magnetite and augite which are embedded in it. The crystalline

† Trans. Edin. Geol. Soc., vol. viii., p. 363 (1905).

‡ Quart. Journ. Geol. Soc., vol. xxxix., p. 459 (1883).

§ "The Tertiary Igneous Rocks of Skye," p. 342 (1904).

‖ "The Tertiary Igneous Rocks of Skye," p. 350 (1904).

ingredients of the rock are hypersthene, augite, plagioclase felspar, and magnetite. The large felspars are tabular on the brachypinakoid, and contain rounded glass enclosures sometimes large and isolated, at other times small and densely crowded together. Their idiomorphism is often very perfect, and they are of the vitreous or microtine habit. The smaller felspars, much more numerous, are scattered irregularly through the glassy base, and are mostly incomplete growth forms. They are nearly square in cross section and about five times as long as broad. Many of them have a large core of glass which presents a quadrate shape when cut transversely, following closely the outlines of the enclosing crystal. Longitudinal sections have forked ends or the form of a capital letter H, others have enclosures of irregular character; and while the lateral faces of the crystal are perfect, it is rare to find one with a well-defined termination. Determinations of the phenocrysts in various ways, and of the smaller crystals mostly by Becker's method, showed that the felspar was labradorite (Ab 40/An 60). Large crystals of hypersthene are less numerous than those of felspar, and are mostly idiomorphic prisms with the usual octagonal cross sections, and the prismatic cleavage more pronounced than the pinakoidal. The colour is greenish-brown, with pleochroism from pale green to reddish-brown in thin slides. As there was some doubt about the mineral, crystals were isolated from a crushed powder and proved to be highly pleochroic rhombic pyroxene. Brown augite, in smaller crystals, is more common and belongs mostly to a later period of crystallisation. It forms long prisms with idiomorphic cross sections and ragged ends; many of them are simply twinned on the orthopinakoid. Enclosures of glass and iron oxides are frequent in the pyroxenes, though less abundant than in the felspar. Magnetite occurs in large and small octahedra, and the rock contains also a few prisms of violet-coloured apatite.

Camptonite.—Quite the most interesting of the dyke rocks of this sheet is a camptonite which occurs at the south-west end of Rudha nam Faoileann, Scarba.* This dyke weathers in a spherulitic or nodular manner, resembling one of the variolites above described, and its exposed surface is covered with spheroids which measure a quarter of an inch in diameter. There is nothing in the microscopic section, however, to explain this peculiarity, which is by no means characteristic of the camptonites. The dyke is fine-grained and not conspicuously porphyritic, but shows small white spots (ocelli). It proves to consist essentially of olivine, brown hornblende, and titaniferous augite, with lesser amounts of felspar, apatite, iron oxides, and analcite. The olivine, in grains half a millimetre in diameter, is entirely replaced by serpentine and iron oxides. The hornblende is more abundant than the augite; its small idiomorphic prisms are about five times as long as broad, and show the usual six faces in cross-sections, but are not always

* This camptonite dyke runs east and west and may be of pre-Tertiary age. —B. N. P.

perfectly terminated. The highest extinction angles measured in longitudinal sections were 16 degrees. The pleochroism ranges from dark brown to yellow brown, and is that which is usual in the hornblendes of basaltic rocks. The augite is purplish brown, dichroic, and frequently has zonal and hour-glass structures; the edges are usually more deeply coloured than the centres. It occurs in small short prisms, often with a high degree of idiomorphism, but most of them are surrounded by hornblende in parallel growth. Felspar is not very abundant. It forms prisms yielding lath-shaped sections, and belongs partly to andesine and acid labradorite, but alkali felspars occur also, as may be proved by their refractive index. A turbid interstitial material is present in small patches mixed with acicular and fibrous felspars. This material is probably a decomposed and devitrified glass. There are small irregular areas of clear and isotropic analcite, with a few cloudy patches of the same mineral. From its association with sharply-formed rhombohedra of calcite, this mineral is presumably secondary. Very long, pointed needles of apatite are numerous, and penetrate all the other ingredients of the rock except the iron ores. The latter, to judge by their outlines, appear to be mostly magnetite (probably titaniferous).

The structure of this rock is panidiomorphic, as all the original minerals are idiomorphic except the fibrous felspars which lie in the devitrified glass. The only phenocrysts are the olivines, and they are small. The ocelli, which are a characteristic feature of the rocks of this group,* are well represented, but not of large size. Most of them measure about a millimetre in diameter; their outlines are rounded, and they are principally composed of turbid glass with plumose, sub-radiate tufts of felspar. Larger felspars also occur in them as diverging prisms; areas of analcite and of calcite are almost constantly included in these ocelli either centrally or near their margin. Olivine and augite do not occur in these circular patches, but near their outer borders small prisms of hornblende may very commonly be seen, not differing in form or in optical properties from those which occur in the rest of the rock.

J. S. F.

* Berwerth—Mikroskopische Strukturbilder, Lf. ii. (1897).

CHAPTER IX.

Faults.

Faults of two types enter into the structure of the present area, viz., Overthrust Faults, due to compression, and Normal Faults, due to extension or unequal subsidence of the region.

Overthrust Faults.—As mentioned in previous Chapters, small overthrust faults other than the small gliding planes of strain-slip cleavage are not uncommon among the metamorphic rocks, especially in the quartzites of Jura, Scarba, Lunga, and the Garvellach Isles. They occur on the weak limbs of overfolds, and their inclination is usually more or less parallel to the foliation planes of the rocks which they traverse. As a rule the amount of displacement is but slight, but in one case, as measured by the shift of a vertical epidiorite dyke, it was as much as half a mile. These thrust faults were probably produced towards the end of the period of great earth-movements which foliated the metamorphic rocks of the region. They are certainly older than Lower Old Red Sandstone time, as they are often occupied by lamprophyre sills, the product of the later phases of the vulcanicity of that period. The outcrop of one of these faults is indicated by the lamprophyre sill which crowns Cruach Scarba, the highest hill on the island of that name. Several others also coincide with lamprophyre sills on the south coast of Scarba, a little to the east of the whirlpool of Corryvreckan.

Normal Faults.—The normal faults fall naturally into two categories according to their trend, viz., (*a*) those which coincide with the strike of the structures of the metamorphic rocks, and may be truly called strike faults, and (*b*) those which cut these structures nearly at right angles, and for convenience of description may be named transverse faults.

(*a*) The most prominent of the strike faults is one which traverses the islands of Eilean Mor, Lunga, Scarba, and part of Jura in a nearly north and south direction. The downthrow is towards the west, but there is probably also a considerable amount of lateral displacement, for while on Scarba, Lunga, and Eilean Mor nearly all the structures of the older rocks on the east side of it coincide in direction with the outcrop of the fault, those to the west are obliquely truncated by it. An epidiorite dyke, in a very crushed and attenuated condition, is found at intervals along its course, which is also marked by a considerable amount of crush material derived from the sedimentary rocks. The abundance of epidiorite dykes on the west and their entire absence on the east side of this line of fracture is a fact of some significance.

Consideration of the above facts suggests that this line of disloca-

tion was probably caused by the same agency which produced the deflection of strike in this region, and that it is one of the great wrench-faults which affect the Central and Northern Highlands. The best known of these is the Loch Tay fault, which is known to be older than the deposition of the Lower Old Red Sandstone of the Central Valley.

A second strike-fault of some magnitude crosses the ground north of Loch Melfort from Kilchoan Bay to the edge of the map. This fault throws down to the south-east and repeats the volcanic pile of the Lorne plateau. It is therefore later in date than that already described, although its direction has been probably determined by an older line of fault, dating from the period of regional metamorphism of the country. A number of minor fractures of this type, most of which are too small to be shown upon the map, occur in different parts of the area. On the whole these appear to be of earlier date than the majority of the transverse faults next to be described.

(*b*) *Transverse Faults.*—These are not only more numerous than the strike faults already mentioned, but are much more easily detected on the ground, although the fault lines are often occupied by Tertiary basalt dykes. B. N. P.

The transverse faults in the Melfort area are probably of the same age as the Tertiary basic dykes, which frequently coincide with them. One of them, accompanied by several basaltic dykes, crosses the Pass of Melfort at the junction of the Eas Tarsuinn with the river Oude, and on the south-west side of the former stream an inlier of the older schists is seen terminating abruptly against it, while further to the north-west it faults a bed of ash intercalated in the lava-flows. Another of these faults coincides with the hollow on the south-west side of the Druim Barr na Coille escarpment. Lines of crush, with a general east and west trend, are occasionally seen in the Tom Soilleir mass of diorite, and the Tertiary dykes are often diverted along them. H. K.

Another important transverse fault with a downthrow to the north-east crosses the volcanic plateau, which it bounds for part of its course between Kilchoan Bay and Seil Sound. South of Loch Melfort the same fault passes from Kames Bay across the granite *massif* of Tom Soilleir into the adjoining Sheet (37), where it has been traced into the neighbourhood of Loch Awe. Much of this fault-line also is filled in with basalt dyke material which has been injected into the wide fault-breccia that occupies the line of fracture.

The Kilmartin area is traversed by a whole series of faults of this description. Many of these can be traced across the Craignish promontory, and some pass yet further into the more northerly islands, where their course is often only shown by the basalt dykes which have taken advantage of them. Even in these cases they are seen to shift the outcrop of the epidiorite sills and the various groups of schists of sedimentary origin, even where the structures are steep—an important item of evidence bearing on the small amplitude of the folds. Denudation of the shattered material

along these lines of fracture has given rise to gaps and passes, which are taken advantage of by all the roads which cross the region. One of the most conspicuous of these passes carries the Great North Road across the watershed between the Kilmartin valley and the head of Loch Craignish. B. N. P.

The largest of the transverse faults in the area south of Loch Crinan coincides approximately with the hollow through which has been carried the Crinan Canal, and has further determined the shore of Loch Crinan westwards from Crinan Harbour. A number of other lines of fracture, often marked by zones of shattered rock, also cross this region in a direction at right angles to the strike of the beds.

Numerous faults of this type also traverse the quartzites of Jura, Scarba, and the more northerly islands.

B. N. P., J. B. H., E. B. B.

In the area north of that with which we are at present dealing, many of these transverse faults traverse not only the rocks of the Old Red Sandstone volcanic plateau, but also the granites and dyke rocks attributable to the last stages of vulcanicity of that period. Most of these fractures were doubtless produced at the time when a wide region, of which the present area is but a small portion, was subjected to tension in a north-east and south-west direction during the great outburst of volcanic activity in Tertiary times in the Western Islands.* B. N. P.

* For full description see : Sir Arch. Geikie—"Tertiary Volcanic Rocks of British Islands," *Proc. Roy. Soc. Edin.*, vol. vi., pp. 81-75 (1869); also "Ancient Volcanoes of Great Britain," vol. ii., by the same author.

CHAPTER X.

Pleistocene and Recent.

Glacial Deposits.

Ice Movements and Glacial Striæ.—The land area of Sheet 36 bears evidence of the westerly seaward passage of an ice sheet which during its maximum extension not only filled the sounds and sea lochs, but, notwithstanding the superiority in height of the central ridge of Jura and Scarba to any part of the mainland, also overrode the outer islands.

A study of the striæ placed on the map shows that this general westerly movement was subject to considerable variation.

After leaving the mainland the ice, instead of spreading out fan-wise, as might have been expected, over the Continental shelf, appears to have converged towards the west, the movement indicated by the striæ being south-west on the Garvellachs, nearly due west on Scarba, and to the north of west over the central ridge of Jura. This convergence was doubtless caused by the compression of the ice which passed over the present area between two powerful ice-streams, one flowing south-westwards through the Firth of Lorne, the other passing north-westwards over Kintyre, Knapdale,* and Islay, and as far even as Colonsay. Besides these more general movements, there is everywhere evidence of local variation due to the form of the ground.

In the district around Kilmelfort the striations on the ice-worn rock surfaces have a general east and west direction, varying up to as much as W. 45° S., which is the trend of striæ a mile to the south-west of the village. The ice is thus shown to have moved westwards, and to have inclined to the south of west and even to south-west, according to the form of the ground. The most noticeable departure from this general trend was observed in the Pass of Melfort, which runs nearly north and south, and where the striæ follow the same direction. As a rule these ice-markings have disappeared from the exposed surfaces of the knolls and crags of andesite, owing to the weathering of these volcanic rocks. But along the sides of the sea-lochs between tide-marks they are often well preserved. B N. P.

On the summits of the hills east of the Barbreck River the striæ point west or W. 10° N., while in similar positions in Craignish the direction is usually towards W. 20° S. The striæ seen on the shores of islands in Loch Craignish indicate an ice-movement down the loch, and on the small islands off the

* Jamieson, T. F., "On the Ice-worn Rocks of Scotland," *Quart. Journ. Geol. Soc.*, vol. xviii., p. 164.

western shore usually run north-east and south-west. This variation of direction at different altitudes shows that while the ice as a whole moved across Craignish towards a point somewhat south of west, there was a heavy undertow in Loch Craignish, due to the lower layers of ice in the bottom of the valley tending to escape down the loch. H. B. M.

Another instance of local deviation is found in the neighbourhood of Kilmartin, where the ice-movement over the north part of the area, as shown by the striæ and the carry of the blocks, was towards the W.S.W., while over the low ground to the south and west of the village the direction changes to west, and on the east shore of Loch Crinan to W.N.W. J. S. G. W.

Similar phenomena have been observed in the neighbourhood of Cairnbaan, where the ice from the Loch Fyne area passed out westwards by Loch Crinan, while the striæ on the south side of that loch indicate a north-west or even more northerly movement. Those met with on the hills to the south of the loch point west or W.N.W. Still further to the south the direction of the striæ varies from W. 10° S. to W. 30° S., evidently denoting an undertow in the direction of Loch Sween and the Sound of Jura.

A striking example is afforded by the island of Scarba, whose culminating point, Cruach Scarba, is 1470 feet in height. The striæ on the top of this hill point a little south of west, but diverge on either side of the hill and converge behind it, assuming once more the direction of those on the summit, clearly showing that in one and the same region different strata of the ice were moving simultaneously in various directions. B. N. P.

On Jura, again, the striæ on the east side of the central ridge point west by south, while on its summit a movement to the north of west is indicated. The evidence of an undertow of the ice sheet down the Sound of Jura is, however, much stronger in the more southerly part of the island. S. B. W.

Boulder Clay.—The main characteristic of the present area is the great exposure of *roches moutonnées* compared with the meagre and sporadic occurrence of glacial deposits, especially in the form of boulder clay. In most parts of the mainland of Scotland it is difficult to decide whether this boulder clay represents the *moraine profonde* of the great ice sheet or that of the later confluent glaciers. The latter, issuing from the Highland glens, coalesced upon the Argyllshire plateau and reached the eastern margin of this Sheet.* Lobes of these confluent glaciers may have entered some little way within it, but there is no evidence that they reached the west coast. Consequently in Jura and Scarba it is easy to separate the moraines of the local glaciers from the boulder-clay of the great ice-sheet.

In the country north of Loch Melfort thin patches of boulder-clay, too small to be shown on a one-inch map, occupy hollows in the volcanic plateau. The clay is grey in colour, and the

*"Geology of Mid-Argyll," *Memoir Geological Survey* (1905), p. 134.

chief boulders it contains are of the same type as the underlying volcanic rocks. Fragments of schist, in a higher stage of metamorphism than any found west of Ben Cruachan, as well as of the granites and porphyrites of that *massif* itself, are also fairly abundant, and thus supply evidence of the ice-carry in accordance with that afforded by the striæ in the present area and the adjoining ground to the east. B. N. P.

In Craignish the boulder-clay is greyish in colour, weathering yellow, and contains boulders of quartzite, phyllite, epidiorite, and porphyrite. It is sparingly distributed as a thin coating on the floors of the hollows, the largest patches occurring between Ardlarach and Duine, near Lunga House, and on the low ground between Barrichbeyan and Turnallt.

Two or three erratics of grey granite were observed on the hills south of Barravulin. All the crags are well glaciated on the east side—obviously that on which the ice impinged. H. B. M.

In the Kilmartin region the glacial deposits other than the fluvio-glacial gravels are confined to the narrow hollows between the numerous N.N.E. and S.S.W. rock ridges. Boulders of granite and schists from the Ben Cruachan country are found throughout the area, and erratics of volcanic rocks identical with those of part of the Lorne plateau north of Loch Awe are also abundant. J. S. G. W.

Small patches of boulder-clay also fill the hollows between the epidiorite ridges south of the Kilmartin valley and the Moine Mòr. What little boulder-clay occurs south of the Crinan Loch is red in colour; boulders of red sandstone are everywhere met with, while others of a type of porphyrite unknown in the region are not uncommon, especially at Ardnoe Point. It is therefore probable that much of the drift in this district has been derived from an area of Old Red Sandstone. J. B. H., E. B. B.

Boulder-clay in minute patches occurs on the inner group of islands east of the Sounds of Jura and Luing, and contains fragments derived from the mainland. On the outer group of islands there are considerable spreads of a grey boulder-clay also full of rocks resembling the phyllites and epidiorites of the mainland. On Jura red sandstone and andesitic fragments like those found in the boulder-clay of the area south of Crinan also occur. The most conspicuous boulders foreign to the island of Scarba are epidiorites, quite unlike those of the native dykes, but similar to those of the Kilmartin region and the country north of Loch Awe.

Erratics of granite, porphyrite, andesite, and epidiorite from the mainland are scattered over the Garvellachs above the limit of the various raised beaches and rock-notches. B. N. P.

Lochs and Rock-basins.—Of the numerous small fresh-water lochs found in the area under consideration, the largest is Loch Coille Bharra, a narrow piece of water about a mile long in the area south of the Crinan Canal. It lies in a long strike-hollow, and is evidently a rock-basin. Draining into the north end of Loch Coille Bharra is another smaller loch, also occupying a rock-basin. To

the east of these lochs there are several others which lie in similar hollows between the epidiorite ridges, and appear to be mostly rock-basins, but have been enlarged by artificial embankments to store up compensation water for the Crinan Canal.

A few small rock-basins are also met with in hollows between the hills to the west and north of Kilmartin. B. N. P.

An uncommon type of rock-basin is met with in Craignish, and is illustrated by three examples lying to the north of Ardfern, viz., Loch na h-Ardlarach, Loch a' Mhadaidh, and Loch na Beiste. These rock-basins lie in hollows eroded along an outcrop of phyllite. The hollows are bounded on the east and west by ridges, which rise 50 feet or more above the level of the lakes. On the tops and flanks of the ridges, rock crops out so continuously that there is no possibility of a buried outlet passing through these ridges towards the east or west. On the north and south sides, where the low ground follows the strike of the phyllites, the rock-basins are bounded by north-westerly basalt dykes, which project above the general level of the ground and form rock-barriers from two to three feet up to 40 or 50 feet high. In some cases the dykes are covered with bright green turf lying close to the rock, whilst in others bare basalt may be traced from one side of the hollow to the other. The streams discharging from the lakes escape by gaps cut through the dykes.

There can be little doubt that the rock-basins owe their origin to the ice-sheet having eroded the phyllites to a much greater extent than it has done the hard basalt dykes. It may be supposed that the work of erosion was greatly assisted by a pre-glacial weathering of the phyllites, the existence of which, however, it is impossible to prove.

The largest of the lochs is only 500 yards long by 240 yards across, and all are being slowly filled up by alluvium and peat. Some of the peat-mosses which mark the site of former lochs are also bounded on one side by the ridge of an outstanding basalt-dyke.

Lochan Druim an Rathaid, which lies three miles north by west of Kilmartin, has no outlet at the surface, but the strong spring issuing on the limestone outcrop 250 yards to the south is no doubt the outlet of an underground discharge from the lake. H. B. M.

It is not only on the land surface that these ice-abraded rock-basins occur. The contour-lines, which on this map are continued down to a depth of 200 feet below Ordnance datum level, show that the floors of the different sea-lochs and of the Sounds of Luing, Shuna, and Seil are studded with basins which, were the land upheaved to the extent of 200 feet, would form lochs much larger in area than any existing on the present land surface. B. N. P.

Phenomena of the Later Glaciation.—It is chiefly in the islands that a discrimination can be made between the phenomena of the earlier and later glaciation. The distribution of striæ and disposition of moraines in the main valleys of Jura show that, after the ice from the mainland had been withdrawn, a system of small glaciers radiated from the high ground and in some cases reached the

then existing sea-level on the west coast. The striæ follow the courses of the valleys, in which both lateral and terminal moraines abound, while peat mosses, representing silted-up lochans, are common especially in the flat-bottomed eastern valleys, in none of which the glaciers reached sea-level. On the west side of the island the valleys are shorter and steeper, and in Glen Garrisdale and the valley of the Allt Loch na Conaire the terminal moraines of the valley glacier appear to merge into the materials of the 100-foot beach. S. B. W.

Moraines are found in a hollow on the south side of Cruach Scarba, the highest point of Scarba Island, but do not descend below the 900-foot contour line.

On the mainland there is no such direct evidence of local valley glaciation, and the only phenomena that can with any certainty be assigned to that period are the sheets of high-level fluvio-glacial gravel laid down by the melt water which escaped from lobes of the great confluent glacier of the Loch Awe basin across the watersheds into the valleys of the Add, the Kilmartin Burn, and the Barbreck River (see *ante*, pp. 6, 7). The gravel terraces near Baroile, in the Rudale valley, contain, in addition to large blocks of hornblende schist, boulders of quartz-porphyry derived from intrusions of that rock in the Add basin to the north-east, the nearest of which is distant at least six miles.

The higher terraces on either side of the Kilmartin valley have also probably a fluvio-glacial origin, and were laid down by overflow water from the east through the Creagantairbh gorge.*

B. N. P., J. B. H.

RAISED BEACHES.

The "Hundred-foot" Raised Beach.—Below Kilmartin village the terraces referred to in the last paragraph merge into the raised beach, of which they may be considered to be contemporaneous delta deposits. Remains of this beach are also found more or less all round the head of Loch Crinan, and a tongue of the same deposit, covered with the deltas of many small streams, passes through the hollow followed by the Crinan Canal to join a corresponding beach which stretches up from Lochgilphead—an indication that the peninsula of Knapdale and Kintyre must have been separated from the mainland in late glacial times. Fragments of this beach, which rarely quite reaches a height of 100 feet above Ordnance datum, are also seen along the coast both north and south of the mouth of Loch Crinan. The beach is also well developed along the coast south of Ardmore Point and round the head of Caol Scotnish, where it seems to rise slightly above the 100-foot level. B. N. P., E. B. B.

In two localities the late-glacial clays have yielded a marine fauna, which has been investigated in each case by Messrs. Crosskey

* "Geology of Mid-Argyll (Explanation of Sheet 37)," *Memoirs of Geological Survey* (1905), p. 139.

and Robertson.* The results of the investigations of these observers may be summarised as follows:—

A little to the south of Duntroon Castle a stiff brown clay, which is covered with gravelly sand, comes to the surface at high-water mark. From this were obtained 33 species of Mollusca, many of which are arctic or boreal forms; also 37 species of Ostracoda, 33 of Foraminifera, and several Polyzoa, Cirripedes, Echinoderms, and Annelids. The most abundant species of Mollusca include such forms as *Leda pernula* Müll.; *L. pygmæa* Münst.; *Mya truncata* Linn.; *Trophon clathratus* Linn.; and var. *gunneri* Loven; *T. truncatus* Ström., and *Pleurotoma pyramidalis* Ström.

The second locality is an artificial section on a promontory on the north side of No. 11 lock on the Crinan Canal, and at a height of 30 feet above sea level. The shells were here confined to a thin stratum in the reddish-brown clay, and were both scarce and fragmentary.

In Craignish remains of this higher beach, consisting of deposits of rolled gravel and sand, and occasionally of silt or clay, are found at several localities, and rise to heights varying between 65 and 90 feet above O.D., but to a rather higher level near Turnallt. In a green clay exposed in the burn below Hill Park, *Littorina obtusata* was found at a height of about 70 feet above O.D. In the burn below Gemmil, on the west side of Craignish, gravel and sand eight feet thick rests on 12 feet of yellow, laminated, sandy clay, containing a few angular stones and small pebbles. The base of the section is 10 feet above the rock-platform of the lower beach. These deposits are unaccompanied by a well-marked rock-platform such as occurs with the lower beach, but evidence of marine erosion at the higher level is not wanting. H. B. M.

"*Fifty-foot*" *and Lower Raised Beaches.*—Conspicuous among the raised beaches at lower levels than the "Hundred-foot" is one which, though rarely exceeding a height of 40 feet above O.D., is believed to represent the 50-foot beach of Loch Linnhe. The rock-notch which accompanies this beach is perhaps one of the most striking features of the seaboard, fringing, as it does, every exposed coast-line and encircling every rocky holm and outlying skerry. The deposits of this beach-level cover considerable areas at the heads of the sea lochs, especially on Loch Crinan, where they underlie the peat of the Moine Mhòr. Elsewhere they are usually taken advantage of for cultivation.

The 50-foot beach is well defined throughout the Kilmartin district, and extends up the valley of the Kilmartin Burn to within a mile of the village. A section exposed on the river Add near Drumore shows 10 feet of horizontally-bedded gravel resting upon stiff grey boulder-clay. B. N. P., J. S. G. W.

Along the coast south of Loch Crinan a flat feature is often present just above the high-water mark of spring tides, which may possibly indicate a further halt in the elevation of the land. This

* "The Post-Tertiary Fossiliferous Beds of Scotland," *Trans Geol. Soc. of Glasgow*, vol. iii., pp. 327-331 (1871).

slightly-raised beach is found in situations where it cannot represent an ordinary alluvial deposit. E. B. B.

On both sides of Craignish there is a well-marked rock-platform, broad and low where cut in the phyllites, narrower and rather higher in epidiorite, but nowhere probably more than 30 feet above Ordnance datum. The platform is sometimes covered with gravel, and sometimes replaced by a terrace of gravel, sand, or clay. The surface of the gravel-terrace is usually 30 to 35 feet above O.D., but when followed up the Barbreck River it merges into the first river-terrace near Barbreck House. In the burn section opposite the Inn at Ardfern, the shells given in the following list were found in a green clay about 12 feet above ordinary high-water mark :—

Echinus lividus? Lam. (spine).
Modiola modiolus (Linn.).
Mya arenaria Linn.
Mya sp. (fragment).
Tellina calcarea Gmel.
Buccinum undatum Linn.
Littorina littorea (Linn.).
Trochus cf. *tumidus* Mont.
Balanus porcatus Da Costa
Also *Littorina obtusata*, *Mytilus edulis*, and *Cardium edule*, which were identified in the field.

A green clay exposed beneath river-gravel in the bed of the Barbreck River at its mouth contains a more abundant fauna. The following species, as well as those in the preceding list, were identified by Dr. Ivor Thomas :—

Foraminifera (*Miliolina* sp., etc.).
Nullipore.
Echinocyamus pusillus Leske
Echinus lividus? Lam. (spines).
Echinus sp.
Axinus flexuosus (Mont.).
Cardium exiguum Gmel.
Kellia suborbicularis (Mont.).
Lutraria elliptica Lam.
Montacuta bidentata (Mont.).
Nucula nucleus (Linn.).
Pecten sp. (fragment).
Scrobicularia alba (Wood).
Buccinum undatum Linn.
Cœcum glabrum (Mont.).
Cerithium reticulatum (Da Costa).
Lacuna vincta (Mont.).
Littorina littorea (Linn.).
Littorina sp.
Homalogyra?
Hydrobia ulvae (Penn.).
Rissoa membranacea (Adams), var. *venusta* Phillipi
Rissoa reticulata (Mont.).
Rissoa striata (Adams).
Skeneia?
Trochus sp.
Utriculus sp.
Ostracoda.

The green clay is here just below high-water mark of spring tides, but the fauna proves that it was deposited below low-water mark. Litoral forms such as *Littorina littorea* are rare. The absence of arctic species shows that the clay is younger than the "Clyde Beds," and it may be referred doubtfully to the period of the 35-foot beach of this district. H. B. M.

ALLUVIUM.

Fresh Water Alluvium.—Fresh water deposits other than the high-level fluvio-glacial gravels occur as terraces along the course of the principal streams. In the Kilmartin and Add valleys the

denudation of the fluvio-glacial gravels and the materials of the older beaches have afforded a large supply of sediments to the various river terraces and corresponding beaches that enter into the great plain produced by the silting up of the Crinan Loch. A similar alluvial plain lies near the foot of the Barbreck River, the result of the silting up of Loch Craignish. B. N. P.

Peat.—A wide expanse of heather-covered peat forms the well-known Crinan Moss or Moine Mhòr. The extent of this moss has, however, been largely reduced during the last eighty years, and considerable areas have been brought under cultivation. The western extremity of an extensive tract of peat lying between Lochgilphead and Carnbaan falls within this sheet, and is bounded on the south by the Crinan Canal. Many of the hollows in the sedimentary rocks in Craignish, Kilmartin, and the county south of Loch Crinan are covered with peat, which in many cases conceals the alluvial deposits of drained or silted-up lochans. Considerable patches of peat are also found on the high ground on either side of Loch Melfort, and upon the islands of Jura and Scarba. B. N. P., J. B. H.

CHAPTER XI.

Economics.

METALLIFEROUS ORES.

Kilmartin.—More than 100 years ago mining operations for copper were carried on at the top of the hill close to the old road which crosses from Upper Largie to Old Poltalloch. The veins are small and occur in a large epidiorite sill. They were first opened out by shallow trenches; afterwards a small water level was driven into the hill, and a shaft sunk from the hill face above. The ore is chalcopyrite with a little black oxide of manganese. The chief vein is about four feet in breadth, and the walls are lined with calcite and quartz crystals. The vein face at the end of the water level is covered up and quite concealed by stalactitic material. Some of the ore extracted from the mine is still lying inside the ruined store-house, and, judging from these specimens, the vein appears to have been a good one. An analysis of one of these lumps made by Dr. Pollard gave the following results:—

Copper,	30·31 *per cent.*	
Silver,	1 dwt. 7 grains	} *per* long ton.
Gold,	6 grains	

The ore was shipped at Port na Moine, on Loch Craignish, and conveyed south for smelting.

Seil.—Blende, galena, and chalcopyrite have been reported to occur in small strings or pockets in the epidiorite sill which runs through Seil, Torsay Beag, and Luing, but the quantities found have not been sufficient to induce development. J. S. G. W.

ROOFING SLATES.

The only important mineral industry is the manufacture of roofing slates from the Black Slates of the islands of Easdale, Seil, Luing, and Belnahua. It is often said that the quarries have been in operation for 300 years, but at first they were worked only on a small scale by the local tenants and crofters. The working of the slate as a commercial concern dates from 1748, when a company was formed to manufacture roofing slates at Easdale.

When Robert Jamieson* travelled up the West Coast at the end of the eighteenth century he found slate-quarries at the northern end of Jura, and on Belnahua, Seil, and Easdale. He

* "Mineralogy of the Scottish Isles"; Edinburgh (1800), vol. i., p. 191.

states that the Easdale quarries shipped 5,000,000 slates annually (roughly 6000 tons), and employed 300 workmen. From this period one or more quarries have been worked either by companies or by private individuals.

The following statistics of the production of roofing-slate in Argyllshire, which also includes the quarries at Ballachulish, are quoted from the "General Reports and Statistics on Mines and Quarries":—

Year.	Quantity in Tons.	Value in £.
1900	25,713	51,947
1901	26,446	51,805
1902	27,531	54,371
1903	24,439	48,309
1904	32,336	59,247
1905	17,786	38,141
1906	24,323	45,303

The fluctuation in the output is due largely to labour troubles at Ballachulish.

Apart from two small quarries situated immediately to the north of the margin of the Sheet, there are at the present time six quarries in operation worked by three parties. During 1906 these quarries gave employment to 352 persons, and thus (making due allowance for the wives and families of the workers) afforded the means of livelihood to a considerable number of people, in what is otherwise a sparsely-populated pastoral district.

The product of the quarries is solely roofing slate, no attempt being made to create a regular supply of slate-slabs or other slate articles.

The Slate Belts.—The chief belt of slate rock is the broad outcrop of Black Slates which runs southwards from Seil and Easdale through Belnahua, Luing, and the east side of Scarba and Jura. Slates are now raised only from quarries on this outcrop. They have, however, been quarried in former years from the narrow belt of black slate which runs through Shuna Island, at the north-east corner of Jura, and also from the outcrops east of Cairnbaan on the Crinan Canal. In the lenticular outcrops which run through the Kilmartin district the slate-rock appears to be thinner than it is to the west, and contains in many places thin intercalations of quartzose layers. They are almost everywhere so much affected by strain-slip cleavage as to be useless for the manufacture of roofing slate.

It is quite improbable that green slates could ever be raised from the Craignish phyllites. Even if any considerable belt of uniform rock could be found sufficiently free from strain-slip cleavage, the phyllites themselves are too soft for the purpose.

The Slate Rock.—The slate rock is very fine-grained, blue-black or black in colour, and quite free from the ribbons, spots, and blotches which disfigure some slates. As Prof. James Nicol* first

* "On the Slate Rocks and Trap-veins of Easdale and Oban," *Quart. Journ. Geol. Soc.*, vol. xv. (1859), p. 110-116.

Slate Quarry on Easdale Island.

Large cleavage face on the left, with wrinklings due to strain-slip-cleavage. Structures parallel to the line

pointed out, the slates are split along a true slaty cleavage, which is due to the parallel arrangement of the minute mineral constituents of the rock. Owing to the feeble development of mica, the cleavage faces are only slightly lustrous.

In each quarry a succession of beds is worked, from two to six feet thick individually, the combined thickness varying from 20 to 70 feet. The beds vary slightly in colour and grain, the chief differences noticed by the ordinary observer being variations in the quantity of pyrites, the glossiness of the cleavage faces, and the amount of puckering and frilling on the cleavage-planes due to the incipient development of strain-slip cleavage.

The presence of *pyrites*, which occurs sometimes in small strings and bunches, but most often in $\frac{1}{16}$ to $\frac{1}{4}$-inch cubes, affects the value of the slate in several ways. It varies greatly in quantity, being most abundant in the hard blue-black slates and wanting in certain black beds, which are more earthy than the normal slate. The latter, if used for roofing, are found to become blotchy and lose their colour, and at the same time show signs of decay. It is probable that in these beds the iron sulphides are in a finely disseminated state (just as in the blue-black muds now accumulating on the sea-floor), and oxidise slowly on exposure to the air. In the pyritous slates, on the other hand, the iron sulphides have segregated and crystallised out in stable crystals of pyrites. Hence the pyritous slates maintain their colour and strength, a well-known fact which has given rise to the saying—"The best slate-rock contains pyrites." But there are beds of good slate-rock in the district which contain little or no pyrites.

The presence of the pyrites hinders the perfect cleaving of the slate, and no doubt slightly increases waste in manufacture. Whilst in some beds (*e.g.*, in the quarry on Belnahua) the pyrites is crushed out into lenticles and is surrounded by small "eyes" of quartz, it most often occurs in well-formed cubes, which have clearly grown after the movements which resulted in the cleavage and strain-slip cleavage had ceased. Hence it may be concluded that they were formed, like the large crystals of actinolite and biotite in many schists, during the later stages of metamorphism. The beds containing the crushed pyrites naturally cleave a little more freely than those with large cubes. As the pyrite-crystals do not decompose appreciably even in a town atmosphere, their presence in the finished slate is not objectionable on that account. The projecting angles of the cubes, however, prevent the slates from lying flat on the roof, with the result that it is liable to be leaky, and the slates are more easily stripped in a high wind. But in many beds the cubes regularly break across in the plane of the cleavage, so that this objection does not hold.

The *joints* play an important part in the quarrying of the slate, but there is no very regular set continuous through a thick series of beds. The dip-joints are usually spaced every two to six feet, with a strongly-developed one every twelve feet or so. They often hade from 5° to 10°, generally to the north, but sometimes to the south. The strike-joints are much less regular and always hade

westwards. Sometimes there are two ill-developed sets of strike-joints, one of which hades to the west and the other to the north-west.

Folding and Cleavage.—The character of the folding of the beds in the district has been described in a previous chapter, and need not be repeated, beyond saying that the beds are thrown into folds which recline towards the W.N.W., whilst the cleavage dips towards the E.S.E. at moderate angles (45°-65°). In spite of the complexity of the folding, the small differences in lithological character between the beds, and the highly-cleaved state of the rock, the quarrymen are perfectly well aware of the nature of the folding and of its relation to the cleavage. They use their knowledge in several ways for the economic working of the slate, and give names to the different parts of a fold. When a series of beds dips at about 45° to the E.S.E., and is crossed by the cleavage (Gaelic *sgoltadh;* pronunciation nearly equals "skoltje") dipping at about the same angle and in the same direction, the beds are said to be on the *sgriob* (pronunciation nearly equals "skreep"). It is a recognised rule that if beds on the *sgriob* be traversed towards the west, they will flatten and form a *bonn* (pronunciation nearly equals "bown"), and then turn over and dip downwards vertically, or at a high angle to the E.S.E. (Fig. 7.) The vertical or overturned limb of the fold is

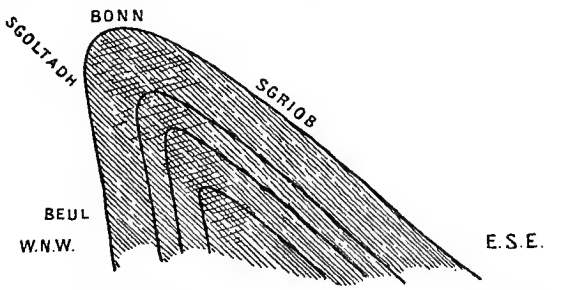


Fig. 7.
Section illustrating Gaelic names in use in the Slate quarries.

called *beul* (pronunciation nearly equals "byel"). Further, it is well known that a bed of slate (locally called a "seam" or "stone") which dips to the E.S.E., and is cut off at the surface, should be looked for towards the west, where it will be found again dipping vertically or at a high angle to the E.S.E.

It is clear from Fig. 7 that a given bed can yield larger slate-slabs on the *sgriob* (where the bedding is nearly parallel to the cleavage) than on the *bonn* or *beul*. This is important in the case of thin beds, for whilst large slabs may be obtained where the bed is on the *sgriob*, the slabs from the *bonn* or *beul* may be too small to be worth splitting into slates.

In other parts of the district where beds of different composition are involved in a fold, it has been observed that the folds have a slight pitch, which is generally towards the south. This pheno-

menon is very difficult to observe in a nearly homogeneous group like the Black Slates. Nevertheless the slate-workers have recognised that the folds pitch to the south, and usually express the fact by saying that a *bonn* rises to the north. This is of practical importance, because a flat bed at a small depth cannot be worked far to the north, unless the ground rises sufficiently in that direction to keep it on. A further effect of pitch is to divert the strike of the bedding from the strike of the cleavage. In the quarry at Toberonochy this divergence amounts to nearly 20° on the limb of a fold.

Some Causes of Waste in Quarrying.—More slate-rock is rendered useless for the manufacture of roofing slates by the strain-slip cleavage than from any other cause. The nature of this cleavage has already been explained on pp. 14-17. In the slate-rock of Easdale and Luing it is most strongly developed where the beds turn over sharply on the crest or in the trough of a fold, a good example being exposed on Easdale Island beside the tramway between the two deep quarries. Hence beds on the *bonn* are often not worth working.

The slaty cleavage itself, apart from the strain-slip cleavage, is sometimes deflected when it reaches the edge of a bed, and thus causes waste, because slates cannot be split from rock with a bent cleavage. The greatest loss from this cause appears where the planes of cleavage and bedding are inclined at considerable angles (45° or more), as in the trough or on the crest of a fold. In such cases the cleavage planes at a distance of two to six inches from the edge of the bed bend away sharply from their normal direction so as to stand nearly perpendicular to the bedding planes. Where beds are on the *sgriob* the cleavage usually maintains a constant dip through successive beds, but sometimes at the edge of each bed it tends to lie more nearly parallel to the bedding. There is, however, but little loss in the latter case.

Two or more slate-bands, which are separated by a small thickness of worthless rock, are often worked in the same quarry. The worthless rock may be due to the slate occurring in very thin beds, to its tendency to split along the bedding, or to the presence of crush-belts filled with strings and pockets of quartz. The latter mineral is probably derived from the solution and re-deposition of the siliceous matter of the slate, but in some cases may have been formed from quartzite beds. There is, however, little rock of this nature in association with the slate-rock worked at the present time.

The slate-rock in the neighbourhood of the thin bands of black limestone, which always occur in the Black Slates, is not of good quality, but beds of very good slate-rock are found a short distance away. The limestone beds seem to have been used with success in the past in tracing out the good beds of slate-rock.

The slate-rock adjoining the N.N.E. porphyrite and lamprophyre dykes and the north-westerly basalt dykes is seldom visibly affected by contact-alteration, but its cleavage has been sealed up. The rock then tends to break along a close-set system of joints and is consequently useless for making roofing-slates.

In none of the quarries is account taken of the amount of waste rock, so that it is impossible to estimate the loss due to quarrying, splitting, and dressing, but it is probably well over 85 per cent. All the quarries are suffering from the results of injudicious dumping of waste rock by the older workers. Good beds of slate have been covered up, and are now being opened up again by the removal of 20 to 30 feet of rubbish. The undesirability of this proceeding is now more fully realised, and waste rock is generally tipped into the sea.

The Quarries.—All the quarries are opened on low ground close to the sea, and the larger ones are 90 to 120 feet deep, thus being excavated in some cases 100 feet below high-water mark. The old quarry at Ellanbeich (Seil Island), which was drowned out by an inrush of the sea during an exceptionally high tide in 1881, had been worked to a depth of 260 feet.

The district having been heavily glaciated, there are usually no superficial deposits to be removed, and the rock is fresh to within a few feet of the surface, where, however, it becomes shattered and iron-stained. It is noticeable that where the beds are vertical (*beul*), they are shattered and stained to a greater depth than usual.

On Easdale a large quarry at the north-west corner of the island and on the site of old workings is wrought by the Easdale Slate Quarries Co., Ltd. The slate-rock is considered by those concerned with the working of the quarry to be the same band, repeated by folding, as that formerly wrought at the east end of the island and on Ellanbeich (Seil Island). The cleavage dips at 55° towards E. 10° S., and the bedding is vertical, but slightly undulating, and strikes N. 30° E. The dip-joints trend N. 80° W. and hade about 18° to the north, and are usually three to four feet apart. The wavy lines due to strain-slip cleavage are somewhat strongly marked, and dip at 25° to the south on the cleavage faces.

At Balvicar, on the east side of Seil, a large quarry with many beds of good slate-rock, and a small quarry recently opened on the strike of older workings, are worked by Messrs. A. & J. MacLean of Cullipool, who also have quarries at Cullipool and Toberonochy on Luing, and a quarry on Belnahua. At Balvicar both the nature of the folds and their pitch to the south are very well seen. The slates are smooth and blue-black.

At Cullipool the slates are wrought on two outcrops, considered to be the same bed repeated by a fold. In both cases the slate-rock is thick and very uniform, and dips to the E.S.E. The pyrites crystals, which are not abundant, regularly split across with the cleavage of the slate. The cleavage dips at 50°-55° to E. 20° S. The dip-joints are well developed and strike N. 60° W. They hade 5° to the north, and are spaced at intervals of six to twelve feet.

In the Breadalbane Quarry at Toberonochy the slate is particularly free from pyrites. There are three chief belts of slate-rock, the thickest of which was estimated to be 70 feet thick. Most of the beds are from two to five feet thick, and dip at 45° to E. 3° S. The cleavage dips at a slightly greater angle, 57° to E. 20° S.

In the quarry on Belnahua Island the beds are dipping very

regularly at 35° to E. 23° N., whilst the cleavage dips east at 47°. There are three chief belts of slate-rock separated by beds, which split along the bedding rather than along the cleavage, a phenomenon apparently due to the development of a strain-slip cleavage parallel to the bedding. The main dip-joints strike W. 5° N. and hade 5° to 10° to the south. They occur every 10 to 15 feet, with less continuous dip-joints between.

Near Port Mary, at the north end of Luing, a quarry is worked by Arch. Maccoll, Esq., in the cliff behind the raised beach. The cleavage dips 60-65° to E. 28° S. At the east end of the quarry the beds are vertical or slightly overturned. Near the floor of the quarry they suddenly flatten and fall with an undulating dip towards the west. The fold pitches southwards at an angle of about 15°. The nature of the folding having been realised, a quarry has been sunk to the westward in order to reach the beds which occur at the eastern end of the quarry.

Method of Working the Slate at the Quarries.—The mode of quarrying varies somewhat with the character of the folding, but whenever practicable the usual method is followed of working in galleries twelve to twenty feet deep cut along the strike and excavated towards the rise of the cleavage.

The men work in "crews" usually of six each, of whom two are rockmen and the remainder splitters and dressers. The "crew" contracts with the Company to work a certain length (10 yards perhaps) of a gallery and to deliver the finished slates to the Company. The "crew" is paid at a certain rate per thousand of slates, and may receive a "bounty" in addition, which varies with the quality of the rock at the particular working face, and the amount of waste rock to be removed. The worse the quality of the rock, and the larger the amount of waste to be removed, the larger is the "bounty." Each contract usually runs for six weeks.

Holes are drilled by hand and the slate blocks lifted by a charge of black powder. The blocks are usually limited by joints and the bedding planes of the "seam." The block is then split along the cleavage by means of a heavy chisel into thick slabs, and these are again split into slabs from one inch to an inch and a half thick. In this condition they are conveyed by the trammers to the dressing sheds. Here the men work in pairs, one man splitting the slabs into slates and the other dressing the slates to shape. For splitting the slabs into slates, a thin chisel (Gaelic, *gilb*) with a fine edge about two inches long is used, and the chisel is driven in by the blows of an iron-bound mallet (*fairchean*). It is known that the slate splits more easily in the direction of cleavage-dip than in the direction of cleavage-strike. The slight waviness on the surface due to the incipient strain-slip cleavage is known locally as the "grain." The relation of this "grain" to the cleavage-dip varies from place to place, but is known to the splitter for the particular slate he is treating. He takes a slab between his knees so that the direction of cleavage-dip in the slate is vertical, places the splitting chisel in the centre, and makes two or three cuts along the centre line. The slab is

then turned round, and by two or three more cuts the split is carried through the slab. Each reduced slab is then split in a similar manner, but with greater care, into two slates.

The dresser sits with an upright iron plate (locally known as "*clach eimile*"), about 8 inches long and $\frac{1}{4}$-inch thick, fixed in a stand in front of him. He places the slate on the edge of the plate and trims it to a rectangular shape with a long heavy knife (*corc sgleit*).

The slates are divided into two classes—"full-sizes" and "under-sizes." The "full-sizes" average 115 square inches in area, but are never less than 7 by 12 inches. The slates vary in thickness from $\frac{3}{16}$-inch to $\frac{3}{8}$-inch and average $\frac{1}{4}$ inch. They are sold by the "thousand" of twelve hundred, forty being added to cover breakages in shipment.

All the quarries being close to deep water, the slates have not to be "trammed" more than a few hundred yards from the dressing sheds to the quays. They are loaded into the ships by the men as part of their contract.

The greater part of the slates find their way to the Glasgow market, a smaller part going to East Coast ports. The supply of slate rock in the district is practically unlimited, so that the output of slates is only determined by the demand for them.

H. B. M.

BUILDING STONE.

A short distance south-east of Craigglass and near the Crinan Canal a quarry has been opened on a massive epidiorite, which yields excellent building stone, capable of being cut into blocks of large size and suitable for resisting the strains in heavy structures.

J. B. H.

The best building-stone on the mainland is afforded by the medium-grained sills of epidiorite, which are slightly foliated. They are fairly regularly jointed at intervals of one to two feet, and thus are easily quarried. Numerous small quarries, opened to supply a local demand, are scattered over the district, but they are not regularly worked. In fact, much of the building material used at the present time is either bricks or sandstone imported from the south.

In the northern part of the district reddish porphyrite of the N.N.E. dykes may be used. This rock is usually much shattered at the surface, but at a depth of a few feet blocks of a very tough close-grained rock are easily obtained.

The diorite of the Kilmelfort district has only been used locally.

BRICKS.

Bricks and tiles of inferior quality were at one time made at Slockavullin and near Balameanoch. At the former locality the clayey alluvium laid down by the Slockavullin burn, where it is

dammed back by a spit of the raised beach, was used in the manufacture of these bricks, which were utilised for some of the houses on the Poltalloch estate.

LIMESTONE.

Lime was formerly produced on a small scale throughout Kilmartin Parish, where, on account of the wide distribution of the outcrops of limestone, the lime required for agricultural and building purposes was locally quarried and burnt on the larger farms. The limestones of Island Macaskin, Shuna, Degnish, and Kilmelfort were also quarried. The lime produced on Island Macaskin and at Kilmelfort was exported to the surrounding districts, where lime could not be obtained locally, but these works have been discontinued for some time, as it is found cheaper to import lime from Lismore and the south.

ROAD METAL.

Road metal is everywhere easily obtained from the epidiorite, porphyrite, basalt, or dolerite intrusions. Limestone and quartzite are also used when the outcrops of these rocks are suitably situated near the road.

The basalt of the north-westerly dykes is no doubt the best stone for the purpose, and owing to the abundance of these dykes is almost always easily available. The porphyrite of the N.N.E. dykes is also good, but the surface is loose, unless it is rolled. As the limestone is relatively soft and binds well, it forms the best surface for an unrolled road, carrying only a light traffic. It is, however, dusty and not so lasting. The side and private estate roads are usually covered with gravel obtained from the raised-beaches and river-terraces. J. S. G. W.

PEAT.

Whilst in many parts of the area peat is cut for fuel in the numerous small mosses which lie in the hollows between the epidiorite and quartzite ridges, the peat in Craignish is of poor quality. On drying it passes to a friable state, which is described as "mossy." It is no longer dug for fuel. H. B. M.

In addition to the use of the peat of the Crinan Moss (the Moine Mhòr) for natural peat fuel, attempts have been made in recent years to manufacture charcoal from the peat for use in steel and iron works. The peat, when disintegrated and moulded into the shape of hollow cylinders, was dried under covered sheds and then converted into peat-coke in special retorts. The tests of this charcoal made in steel and iron furnaces in Glasgow were most satisfactory, but the material could not be produced at the prices offered by the iron and steel trade.

In the year 1901 the British Charcoal Iron Company commenced operations on a much larger scale on a portion of the moss at

Barnakill, near the Crinan Canal, and while their initial experiments appeared to be satisfactory, they did not ultimately prove successful. J. B. H.

AGRICULTURE AND TIMBER.

Arable land is confined to the river-terraces, the raised-beaches, so far as they are cleared of peat, and to ground having a boulder-clay sub-soil. The last-mentioned type of land is cultivated only in small, scattered areas, but a far larger extent was cropped a quarter of a century ago. A five-year rotation—corn, green crop, corn, rye-grass, pasture—is the common rotation of crops in the district.

Apart from superficial deposits, the soils due to the disintegration of so varied a group of rocks as enter into the present area have naturally very different characters. The decomposition of the epidiorite gives rise to a reddish-brown, ferruginous soil covered with a rich pasture, whilst the quartzite produces little but heather and bents. The hollows occupied by the phyllites are usually filled with peat, while a green sward covers the limestone belts. Traces of old cultivation are found wherever limestone and decomposing epidiorite form the sub-soil. Even yet these old cultivated spots form the best grazing grounds, but here, as in nearly every district in the West Highlands, they are overrun with the common bracken, which is being allowed to spread to an enormous extent.

The higher ground is entirely given over to sheep and grouse moor, while Highland and cross-bed cattle are grazed on the lower slopes. In the Kilmartin district the screes accumulating at the foot of the numerous crags are infested with rabbits, which are trapped and sent to market in great numbers.

Water-power derived from the burns is used to drive two meal-mills, and for various purposes on the larger estates, but much more advantage might be taken of the power obtainable by raising the level of the numerous lochs, such as those of Kilmelfort and Craignish.

A considerable area in the Kilmartin district is clothed with timber both young and well matured. The hardwood trees include ash, oak, birch, alder, hazel, elm, poplar, beech, plane, lime, and holly; the conifers, Scotch fir, silver fir, and larch.

J. S. G. W.

APPENDIX.

LIST OF WORKS RELATING TO THE GEOLOGY OF SHEET 36.

1774. Pennant, T. *A Tour to Scotland and Voyage to the Hebrides*, MDCCLXXII, 4to, Chester, Vol. II.

1800. Jamieson, R. *Mineralogy of the Scottish Isles, with Mineralogical Observations made in a Tour through different parts of the Mainland of Scotland, and Dissertations upon Peat and Kelp.* 2 vols., 4to, Edin. Vol. I., pp. 176–196.

1819. Macculloch, J. *The Western Islands of Scotland.* Vol. II., pp. 105–308, Vol. III., Coloured Map of Jura and Slate Isles.

? 1820. Boué, Ami. *Essai Geologique sur l'Ecosse.* (Paris) n.d.

1821. Earl Compton. Description of the Rocks which occur along a portion of the South Coast of the Isle of Mull. *Trans. Geol. Soc.*, Vol. V., pp. 369–374., Pl. 19–21 ; read 1819.

1823. Veitch, Capt. Account of some Terraces or Ancient Beaches in the Isle of Jura. *Trans. Geol. Soc.*, 2nd series, Vol. I., p. 416.

1825. Smith, G. Account of the Sandstone Quarries in the Edinburgh and Glasgow districts, and of the principal Slate Quarries in Scotland. *Trans. Highland and Agricultural Soc.*, Vol. X. (Series 2, Vol. IV.), pp. 94-97.

1840. Macculloch, J. *A Geological Map of Scotland, with Memoir on do.* (Published several years after MacCulloch's death.)

1845. *New Statistical Account of Scotland.* Vol. VII., Argyle (Craignish, p. 49, Easdale Slates, p. 77, Kilmartin, p. 550).

1852. Sharpe, D. On the Arrangement of the Foliation and Cleavage of the Rocks of the North of Scotland. *Phil. Trans.* Vol. CXLII., p. 445, and *Edin. New Phil. Journ.*, Vol. LIII., p. 84.

1855. Bedford, E. J. Notice of some Raised Beaches in Argyllshire. *Quart. Journal Geol. Soc.*, Vol. XI., p. 549.

1858. Nicol, J. *A Geological Map of Scotland.*

1859. Nicol, James. On the Slate Rocks and Trap-veins of Easdale and Oban. *Quart Journ. Geol. Soc.*, Vol. XV., pp. 110–116.

1861. Jamieson, T. F. On the Structure of the South-West Highlands of Scotland. *Quart. Journ. Geol. Soc.*, Vol. XVII, pp. 133–145.

1861. Murchison, Sir R. I., and Geikie, (Sir) A. On the Altered Rocks of the Western Islands of Scotland and the North-West and Central Highlands. *Quart. Journ. Geol. Soc.*, Vol. XVII., pp. 171–232.

1861. Murchison, Sir R. I., and Geikie, (Sir) A. On the Coincidence between Stratification in the Crystalline Rocks of the Scottish Highlands. *Quart. Journ. Geol. Soc.*, Vol. XVII., pp. 232-240.

1862. Jamieson, T. F. On the Ice-worn Rocks of Scotland. *Quart. Journ Geol. Soc.*, Vol. XVIII., p. 164.

1862. Murchison, Sir R. I., and (Sir) A. Geikie. *First Sketch of a New Geological Map of Scotland, with Explanatory Notes.*

1865. Geikie, (Sir) A. *The Scenery of Scotland viewed in connection with its Physical Geology* (London and Cambridge), 3rd ed. 1901.

1871. Crosskey, H. W., and D. Robertson. The Post-Tertiary Fossiliferous Beds of Scotland. *Trans. Geol. Soc., Glasgow*, Vol. III., Crinan, p. 327, Duntroon, p. 328.

1874. Judd, J. W. The Secondary Rocks of Scotland. Second Paper, *Quart Journ. Geol. Soc.*, Vol. XXX., pp. 220-301.

1883. Wadsworth, M. E. Notes on the Lithology of the Island of Jura, Scotland. *Proc. Boston Soc. of Nat. Hist.*, Vol. XXII., pp. 485-489.

1887. Gardner, J. Starkie (with notes by Grenville A. J. Cole). On the Leaf-beds and Gravels of Ardtun, Carsaig, &c., in Mull. *Quart. Journ. Geol. Soc.*, Vol. XLIII., pp. 270–300, Pl. XII–XVI.

1892. Geikie, (Sir) A. Presidential Address. *Quart. Journ. Geol. Soc.*, Vol. XLVIII. Proceedings, p. 95.

1892. Geikie, (Sir) A. *A Geological Map of Scotland reduced chiefly from the Ordnance and Geological Surveys*, with Explanatory Notes. (Edin).

1894. Geikie, James. "*The Great Ice Age.*" 3rd edition (London).

1897. Geikie, Sir A. *The Ancient Volcanoes of Great Britain.* Vol. I., pp. 102, 271, 281, 341. (The Volcanic Rocks of Lorne.)

1899. Hill, J. B. On the Progressive Metamorphism of some Dalradian Sediments in the Region of Loch Awe. *Quart. Journ. Geol. Soc.*, Vol. LV., p. 470.

1899. Geikie, Sir A. (Director-General). *Summary of Progress of the Geological Survey of the United Kingdom for 1898.* (R. G. Symes, Kilmelfort district and Easdale, pp. 49–50, 72, and 169.)

1900. Geikie, Sir A. (Director-General). *Summary of Progress of the Geological Survey of the United Kingdom for 1899.* (R. G. Symes and S. B. Wilkinson, pp. 60–65, 98, 99, 146, 147, 163, and 164. Kilmelfort district and Jura.)

1901. Geikie, Sir A. (Director-General). *Summary of Progress of the Geological Survey for 1900.* (Messrs. Symes, Peach and Wilkinson, pp. 46–50, 70–71, and 141.)

1901. Geikie, Sir A. *The Scenery of Scotland viewed in connection with its Physical Geology.* 3rd edition, London, 8vo.

1901. Hill, J. B. On the Crush-Conglomerates of Argyllshire. *Quart. Journ. Geol. Soc.* Vol. LVII., p 313.

1902. Teall, J. J. H. (Director). *Summary of Progress of the Geological Survey of the United Kingdom for 1901.* (Messrs. Peach, Wilson & Muff, pp. 126–130, 142, 151, and 154–157.)

1903. Teall, J. J. H. (Director). *Summary of Progress of the Geological Survey of the United Kingdom for 1902..* (Messrs. Peach, Wilson, Kynaston, Crampton, Muff, and Bailey, pp. 65–84. A Harker, S. coast of Mull, p. 113).

1903. Macnair, P. The Building of the Grampians. *Proc. Roy. Phil. Soc., Glasgow.* Vol. XXXIV., p. 147.

1904. Teall, J. J. H. (Director). *Summary of Progress of the Geological Survey of the United Kingdom for 1903.* (Messrs. Peach and Bailey, pp. 67–69 and 73–74.)

INDEX.

DESCRIPTION OF PLATE VIII.

PHOTO-MICROGRAPHS OF ROCKS FROM SHEET 36.

FIG. 1.—*Hypersthene Andesite;* Shore ½ mile S.-W. of Kintraw, Loch Craignish, Argyllshire.

(S. 10,632, magnified 28 diameters; ordinary light.)

Large glassy crystals of plagioclase felspar and hypersthene lie in a vitreous matrix which contains grains of magnetite, small prisms of greenish-brown augite, and laths of felspar which have forked and brush-like ends (pp. 83 and 89).

FIG. 2.—*Hyalo-tholeiite;* Sloc an 't Siamain, half a mile north-east of Easdale, Argyllshire.

(S. 13,047, magnified 35 diameters; ordinary light.)

The abundant glassy base of this rock is dark brown; the elongated felspars have frequently glass enclosures near their centres; the augite forms small, nearly colourless, isodiametric grains (p. 87).

FIG. 3.—*Epidiorite;* Hill top on north side of Ardifuar, north side of Loch Crinan, Argyllshire.

(S. 13,041, magnified 12 diameters; ordinary light.)

An example of the coarser epidiorites of this quarter. These rocks are often little sheared, as is evidenced in this case by the perfect preservation of the skeleton ilmenite crystals. The large felspars are slightly cloudy and belong to oligoclase and oligoclase-albite. The original augite is all replaced by pale green amphibole (p. 52).

FIG. 4.—*Epidiorite;* three furlongs east-south-east of Ardifuar, north side of Loch Crinan, Argyllshire.

(S. 13,040, magnified 12 diameters; ordinary light.)

An example of the porphyritic epidiorites of this area, which are often vesicular. The photograph shows a cloudy felspar phenocryst in a groundmass of smaller felspars, chlorite, calcite, and quartz. As the rock is little sheared the igneous structures are well retained. The felspars are oligoclase-albite (p. 53).

FIG. 5.—*Porphyrite;* on shore, one and a half miles south-west of Kilmelfort, Argyllshire.

(S. 10,336, magnified 12 diameters; ordinary light.)

The photograph shows a large crystal of hornblende, surrounded by a border consisting of dark brown, aggregated flakes of biotite. The rock contains also phenocrysts of plagioclase felspar, and the groundmass consists of orthoclase and plagioclase, biotite, augite, and magnetite (p. 73).

FIG 6.—*Porphyrite;* An Cnap, four miles south-west of Kilmelfort, Argyllshire.

(S. 10,339, magnified 35 diameters; ordinary light.)

Two crystals of reddish-brown biotite are surrounded by clusters of grains of pale green augite. One of the biotites is cut transversely, the other longitudinally. The groundmass consists of orthoclase and plagioclase, biotite, augite, and magnetite (p. 73).

Fig. 1.

Fig. 2.

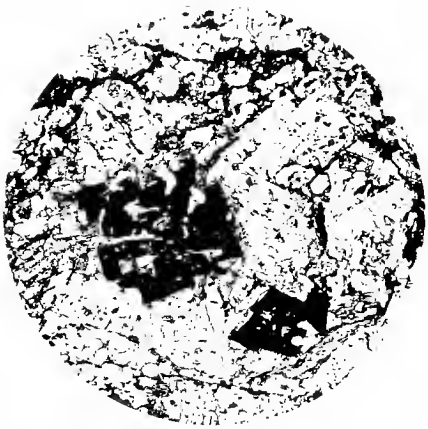


Fig. 3.

Fig. 4.

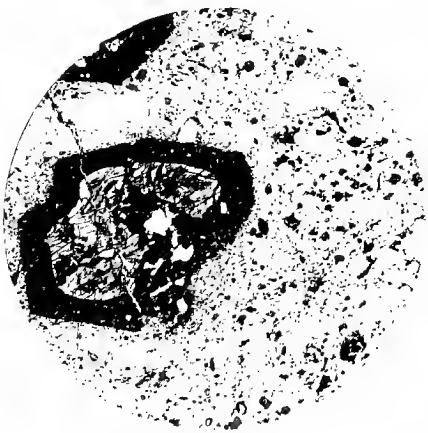


Fig. 5.

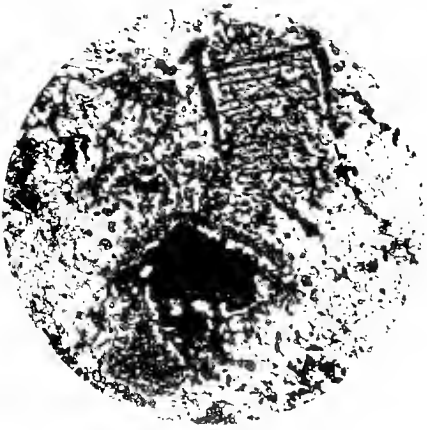


Fig. 6.

Hudleston.

PHOTOMICROGRAPHS.

76. Aberdeenshire, Kincardineshire. 6*s*.
77. Aberdeenshire, S.E. part; Kincardineshire, N.E. corner. 4*s*.
81. Ross-shire, S.W.; Islands of Raasay and Rona, part of Skye. 6*s*.
85. Elginshire, Banffshire, Aberdeenshire (parts of). 6*s*.
87. North-East Aberdeenshire and Banffshire (detached portions). 6*s*.
91. Ross-shire (part of). 6*s*.
94. Ross-shire, Cromartyshire, Sutherlandshire (parts of). 6*s*.
95. Elginshire, Banffshire (parts of). 4*s*.
96. Aberdeenshire, Banffshire (parts of). 4*s*.
97. Aberdeenshire and Eastern Banffshire (parts of). 4*s*.
100. N.W. Ross-shire (part of). 4*s*.
101. Ross-shire, Cromartyshire, and Sutherlandshire (parts of). 6*s*.
103. Sutherlandshire, E. 6*s*.
107. Sutherlandshire (part of). 6*s*.
113. Sutherlandshire, N.W. (part of). 4*s*.
114. Sutherlandshire (part of N.). 6s.
115. Sutherlandshire, Caithness-shire (parts of.) 6s.

II.—Maps on Six-inch Scale, illustrating the Coal-fields.

Edinburghshire.	Sheets 1, S.W., S.E.; 3, N.W., N.E., S.W., S.E.; 4, N.W., N.E., S.W., S.E.; 5, N.E., S.E.; 7, N.E., S.E.; 8, N.W., N.E., S.W., S.E.; 9 (and Haddington 14), N.W., S.W., S.E.; 11, N.W., S.W.; 12, S.E.; 13, N.W., N.E., S.W., S.E.; 14, N.W., N.E., S.W., S.E.; 15, N.W.; 18, N.E.; 19, N.W., N.E. (revised editions). 1*s*. 6*d*. (uncoloured).
Haddingtonshire.	Sheets 4, S.W., S.E.; 9, N.W., N.E., S.W., S.E.; 14, N.E. (revised editions). 1*s*. 6*d*. (uncoloured).
Fifeshire	Sheets 33, 37. 4*s*.
,,	Sheets 24, 25, 30, 31, 32, 35, 36. 6*s*.
Ayrshire.	Sheets 9, 26, 31. 4*s*.
,,	Sheets 7, 8, 11, 12, 13, 16, 17, 18, 19, 22, 23, 24, 27, 28, 29, 30, 33, 34, 35, 36, 40, 41, 42, 46, 47, 50, 52. 6*s*.
Renfrewshire.	Sheets 13, 14, 17. 4*s*.
,,	Sheets 7, 8, 11, 12, 15, 16. 6*s*.
Lanarkshire.	Sheets 1, 2, 3, 4, 5, 10, 49. 4*s*.
,,	Sheets 6, 7, 8, 9, 11, 12, 13, 16, 17, 18, 19, 20. 23, 24, 25, 31, 32, 37, 38, 41 42. 6*s*.
Dumfriesshire.	Sheet 1. 4*s*.
,,	Sheets 5, 6, 7. 6*s*.
Dumbartonshire.	Sheets 19A, 20, 24, 26, 28, including 29. 4*s*.
,,	Sheets 23, 25. 6*s*
Stirlingshire.	Sheets 25, 33, 36. 4*s*.
,,	Sheets 17, 18, 23, 24, 27, 28, 29, 30, 31, 32, 35. 6*s*.
Linlithgowshire.	Sheet 8. 4*s*.
,,	Sheets 2, S.W. and N.W., S.E.; 3, S.W.; 6, N.W., S.W., S.E.; 10, N.W., S.W. (revised editions). 1*s*. 6*d*. (uncoloured).
Perthshire.	Sheets 135, 139, 141, 142, 143. 4*s*.
,,	Sheets 133, 134, 140. 6*s*.

IIa.—Maps on Six-inch Scale, illustrating Structure of N.W. Highlands.

Sutherlandshire.	Sheets 5, 71. 6*s*.
Skye.	Sheets 38, 39, 44, 45. 6*s*.

IIb.—Maps on the Scale of Four Miles to One Inch.

Sheet 16. Galloway and part of Ayrshire, &c.
,, 17. Roxburghshire, Dumfriesshire, &c.
Printed in Colours. 2*s*. 6*d*. *each*.

III.—Horizontal Sections. 5*s*. *per Sheet*.

Sheet 1. Edinburghshire and Haddingtonshire.
,, 2. Edinburghshire, Haddingtonshire, Berwickshire.
,, 3. Peeblesshire, Edinburghshire, Linlithgowshire.
,, 4. Ayrshire Coal-fields (west side).

Sheet 5. Ayrshire Coal-fields (east side).
,, 6. Renfrewshire, Dumbartonshire, Ayrshire.
,, 7. Cheviot and Lammermoor Hills.
,, 8. Clyde Coal-field and Campsie Hills.
,, 9. Ayrshire Coal-fields (Muirkirk and New Cumnock).

IV.—Vertical Sections. *3s. 6d. per Sheet.*

Sheet 1. Edinburgh and Haddington Coal-field.
,, 2. Fife Coal-fields.
,, 2A. Fife Coal-fields.
,, 3. Kilmarnock Coal-field.
,, 4. Clyde Basin Coal-field.
,, 5. Stirling and Clackmannan Coal-fields.
,, 6. Muirkirk, Lesmahagow, and Douglas Coal-fields.
,, 7. Lanarkshire Coal-fields (Rutherglen and Carluke).

V.—Memoirs of the Geological Survey of Scotland.

(1.) General Memoir:—
Silurian Rocks of Britain. Vol. I. Scotland. 15*s.*

(2.) Economic Memoir:—
The Oil-Shales of the Lothians. 4*s.*

(3.) Museum Guide:—
Guide to the Collections of the Geological Survey. 2*d.*

(4.) District Memoirs:—
Cowal, Argyllshire. 6*s.*
East Lothian (out of print).
Central and Western Fife and Kinross. 5*s.* 6*d.*
Eastern Fife. 8*s.*
Skye. The Tertiary Igneous Rocks of. 9*s.*
Islay, &c. 2*s.* 6*d.*
The Geological Structure of the North-West Highlands of Scotland. 10*s.* 6*d.*
Palæontology. The Higher Crustacea of the Carboniferous Rocks of Scotland. 4*s.*

(5.) Sheet Memoirs:—
Sheet 1. Wigtownshire, South-Western Districts. 3*d.*
,, 2. Wigtownshire, South-Eastern Districts. 3*d.*
,, 3. Wigtownshire, Western Districts. 3*d.*
,, 4. Wigtownshire, E. part; Kirkcudbrightshire, portion of S.W. Division. 9*d.*
,, 5. Kirkcudbrightshire, Southern Districts. 1*s.* 6*d.*
,, 7. Ayrshire, South-Western District. 3*d.*
,, 9 Kirkcudbrightshire, N.E.; Dumfriesshire S.W. 1*s.*
,, 13 Ayrshire, Turnberry Point. 3*d.*
,, 14 Ayrshire, Southern District. 3*d.*
,, 15. Dumfriesshire, N.W.; Ayrshire, S.E.; and Lanarkshire, S. 3*d.*
,, 21. Buteshire (Arran, Central, and N. and S. Bute), Argyllshire, Ayrshire (parts of). 4*s.*
,, 22. Ayrshire, Northern District, and parts of Renfrewshire and Lanarkshire. 3*d.*
,, 23. Lanarkshire, Central Districts. 1*s.*
,, 24. Peeblesshire, Lanarkshire, Edinburghshire, Selkirkshire (parts of). 3*d.*
,, 31. Lanarkshire, N.; Stirlingshire, S.; Linlithgowshire, W. 2*s.* 3*d.*
,, 32. Edinburghshire and Linlithgowshire. Out of print. New edition in preparation.
,, 34. Eastern Berwickshire. 2*s.*
,, 36. Seaboard of Mid Argyll. 2*s.* 3*d.*
,, 37. Mid Argyll. 3*s.*
,, 45. Argyllshire, The Country near Oban and Dalmally. 2*s.* 6*d.*
,, 55. Perthshire, The Country round Blair-Atholl, Pitlochry, and Aberfeldy. 3*s.*
,, 60. The Small Isles of Inverness-shire. 4*s.* 6*d.*
,, 70. Inverness-shire. West-Central Skye, with Soay. 1*s.* 6*d.*
, 75. Inverness-shire, Elginshire, Banffshire, Aberdeenshire (parts of). 1*s.*
,, 76. Aberdeenshire, Central. 1*s.*
, 85. Elginshire, Banffshire, Aberdeenshire (parts of). 1*s.* 6*d.*
,, 87. Aberdeenshire and Banffshire (parts of). 9*d.*
,, 97. Northern Aberdeenshire. Eastern Banffshire. 4*d.*

A detailed Catalogue may be had on application to
2 *St. Andrew Square,*